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CH2M Hill, Inc
Mystic Lake Dam,
Bozeman, Montana,
Gallatin County,
MT-880

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PHASE I INSPECTION REPORT
NATIONAL DAM SAFETY PROGRAM

MYSTIC LAKE DAM
BOZEMAN, MONTANA
GALLATIN COUNTY
MT-880

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PREPARED FOR:

HONORABLE THOMAS L. JUDGE
GOVERNOR, STATE OF MONTANA

CITY OF BOZEMAN
AND
BOZEMAN CREEK RESERVOIR ASSOCIATION
(OWNERS)

PREPARED BY:
CH2M HILL
BELLEVUE, WASHINGTON

JANUARY, 1980

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January 1980

SEATTLE DISTRICT
UNITED STATES ARMY CORPS OF ENGINEERS

TABLE OF CONTENTS

Paragraph		Page
	EXECUTIVE SUMMARY.	iv
	PERTINENT DATA	vii
	CHAPTER 1 - BACKGROUND	
1.1	INTRODUCTION	1
1.1.1	Authority and Scope	1
1.1.2	Purpose	2
1.1.3	Inspection.	2
1.2	DESCRIPTION OF PROJECT	3
1.2.1	General	3
1.2.2	Regional Geology and Seismicity	4
1.2.3	Site Geology.	5
1.2.4	Design and Construction History	5
	CHAPTER 2 - INSPECTION AND RECORDS EVALUATION	
2.1	HYDRAULICS AND STRUCTURES.	6
2.1.1	Spillway.	6
2.1.2	Outlet.	7
2.1.3	Freeboard	8
2.2	HYDROLOGY, CLIMATOLOGY, AND PHYSIOGRAPHY	9
2.2.1	General	9
2.2.2	Reservoir Storage and Spillway Discharge. .	9
2.2.3	Estimated Probable Maximum Flood.	9
2.2.4	Flood Routing	10
2.3	GEOTECHNICAL EVALUATION.	10
2.3.1	Dam Embankment	10
2.3.2	Foundation Conditions, Seepage, and Drainage	11
2.3.3	Stability	13
2.4	PROJECT OPERATIONS AND MAINTENANCE	13
2.4.1	Dam	13
2.4.2	Reservoir	13
2.4.3	Warning System.	14

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CHAPTER 3 - FINDINGS AND RECOMMENDATIONS

3.1 FINDINGS 15
3.1.1 Size, Hazard Potential, and Safety Evaluation 15
3.1.2 Embankment Dam. 15
3.1.3 Spillway and Reservoir Capacity 15
3.1.4 Outlet Works. 16
3.1.5 Operations and Maintenance 16

3.2 RECOMMENDATIONS. 17

REFERENCES. 19

APPENDICES. 20

Appendix 1, Design and Construction History Summary, Arthur Van't Hul.

Appendix 2, Report of Leakage Investigation, Mystic Lake Dam, by Northern Testing Laboratories.

Appendix 3, Inspection Report by Theodore T. Williams, P.E.

Appendix 4, Correspondence

PHOTOS
(Bound at end of text)

1 Overall view of Mystic Dam
2 Right abutment and spillway approach
3 Left abutment
4 Spillway and low-level conduit discharge
5 View of downstream left abutment
6 View of downstream slope and ridge between enbankments
7 Closeup of riprap
8 Spillway and low-level outlet discharge

PLATES

1 Vicinity Map
2 Site Plan
3 Spillway Plan and Profile
4 Spillway Rating Curve
5 Outlet Box Section
6 Dam Section
7 Dam Profile

EXECUTIVE SUMMARY

Under contract with the Seattle District Corps of Engineers and with representation from the Corps, the State of Montana Department of Natural Resources and Conservation, the City of Bozeman, and the Bozeman Creek Reservoir Association, CH2M HILL inspected Mystic Lake Dam on June 8, 1979 under the authority of Public Law 92-367. The dam is located on Bozeman Creek in Gallatin County, about 12 miles southeast of Bozeman, Montana.

This report was compiled from information obtained during an onsite inspection, review of construction plans, and analysis of available hydrologic information. Findings were compared with engineering criteria that are currently accepted by most private and public agencies engaged in dam design, construction, and operation.

FINDINGS AND EVALUATION

Mystic Lake Dam is owned jointly by the City of Bozeman and the Bozeman Creek Reservoir Association. The dam and reservoir are located on public land administered by the U.S. Forest Service. The lake is used for storage of municipal and irrigation waters. Use of National Forest land for such purposes is through Special Use Permits. The 48-foot-high earth dam impounds 1,520 acre-feet at top of dam, elevation 6401.9 feet National Geodetic Vertical Datum (NGVD), formerly Mean Sea Level (MSL). On the basis of criteria in U.S. Army Corps of Engineers Recommended Guidelines for Safety Inspection of Dams (Ref. 1), the project is intermediate in size. Based on a visual reconnaissance and engineering judgment, the dam is located such that its failure could cause extensive property damage and possible loss of life. Bozeman is a rapidly developing area and the number of residences that will be affected by a failure of Mystic Lake Dam will continue to increase. Therefore, the project is classified as having a high (Category 1) downstream hazard potential. Inspection criteria (Ref. 1) recommend that an intermediate-sized project with a high downstream hazard potential be capable of safely handling the probable maximum flood (PMF). The PMF is the flood expected from the most severe combination of meteorologic and hydrologic conditions that are reasonably possible in the region.

An estimate of the PMF was developed for the 5.3-square-mile drainage basin. The PMF resulting from the 72-hour general storm has an estimated volume of 5,600 acre-feet and a peak flow of 36,800 c.f.s. The spillway has a maximum discharge

of 780 c.f.s. with the reservoir at top of dam, elevation 6401.9 feet NGVD. The routing of the PMF was started with the reservoir at spillway crest, elevation 6396.2 feet NGVD. The PMF routing indicates that the dam is overtopped when approximately 23 percent of the total flood volume enters the reservoir. The dam is constructed of materials that would quickly erode and fail when overtopped by floodwaters.

A sink hole developed in the dam in July, 1977, and was traced to seepage that carried fine materials into a break in a 12-inch-diameter outlet conduit. The outlet works, consisting of 12-inch-diameter and 16-inch-diameter conduits, was inspected by television camera in 1977, revealing the break settlement of both pipes. Another inspection in 1978 indicated that additional settlement of the 16-inch-diameter conduit occurred after the 1977 inspection. This continued settlement suggests that additional breaks in the conduits will occur.

On the basis of the field inspection and study of hydrologic and operational data, Mystic Lake Dam does not conform to Corps guidelines with respect to discharge and/or storage capacities to safely handle the PMF. Dam overtopping would lead to failure and resultant downstream flood flows that might increase property damage and loss of life. The project has an inadequate spillway. Also, the condition of the outlet conduits, the unknown seepage and foundation condition, the location and condition of the core wall, and the stability of the left abutment need further analysis and correction as required. The project is considered unsafe until the recommended actions are completed.

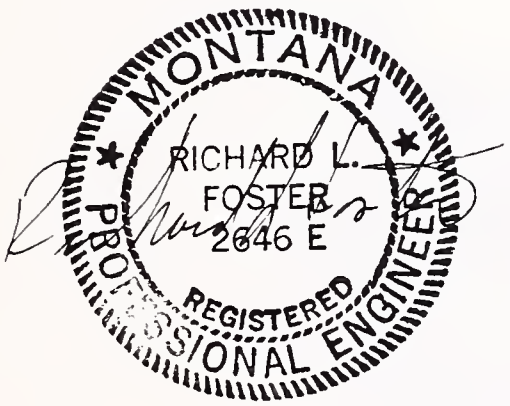
RECOMMENDATIONS

Immediately improve, update, and periodically test the existing emergency downstream warning plan. Immediately take the necessary actions to eliminate known seepage conditions and either rehabilitate or replace existing outlet conduits. Because the PMF used for the dam safety analysis is preliminary and not suitable for design, detailed engineering studies are needed to determine the PMF. Include in the hydrologic studies a hydraulic routing of a dam breach hydrograph to more accurately establish the downstream hazards associated with a dam failure. Also, because the project lacks necessary geotechnical data, complete stability and seepage evaluations of the dam and left abutment slide area are required. The project needs to be modified, as studies indicate, to safely control the recommended spillway design flood with assured stability.

If these recommendations are not accomplished in a timely manner, we recommend consideration be given to removing the dam.

Richard L. Foster

Richard L. Foster
Professional Engineer



PERTINENT DATA

1. GENERAL

Federal ID No.	MT-880
Owner	City of Bozeman
Operator	City of Bozeman
Date Constructed	About 1904
Purpose	Water Supply and Irrigation
Location	Section 30, T3S, R7E and Section 25, T3S, R6E
County, State	Gallatin County, Montana
Watershed	Bozeman Creek
Downstream Hazard Potential	Category 1 (High)
USGS Quadrangle	Bozeman Pass

2. RESERVOIR

Surface Area at Spillway Crest, Elevation 6396.2 feet NGVD.	57 acres
Drainage Area	5.3 square miles
Storage at Spillway Crest, Elevation 6396.2 feet NGVD	1,190 acre-feet
Storage at Dam Crest, Elevation 6401.9 feet NGVD	1,520 acre-feet
Surcharge Storage	330 acre-feet

3. SPILLWAY

Type	Uncontrolled concrete chute
Crest Width	20 feet
Crest Elevation	6396.2 feet NGVD
Capacity with Reservoir at Dam Crest	780 c.f.s.

4. OUTLET WORKS

Conduits	One 16-inch-diameter cast iron One 12-inch-diameter cast iron

Conduit Lengths	178 feet
Valves	One 16-inch gate valve, one 12-inch gate valve, and one 24-inch by 24-inch slide gate located upstream with control at dam crest
Approximate Capacity with Reservoir at Dam Crest (16-inch conduit only)	25 c.f.s.

5. DAM

Type	Homogeneous earth fill with central masonary cutoff wall
Length	440 feet
Crest Width	15 feet
Crest Elevation	6401.9 feet NGVD
Hydraulic Height (Crest to Toe)	48 feet
Upstream Slope	1 V on 2 H
Downstream Slope	1 V on 2 H

CHAPTER 1

BACKGROUND

1.1 INTRODUCTION

1.1.1 Authority and Scope

This report summarizes the Phase I inspection and evaluation of Mystic Dam, owned by the City of Bozeman and the Bozeman Creek Reservoir Association in the State of Montana.

The National Dam Inspection Act, Public Law 92-367 dated August 8, 1972, authorized the Secretary of the Army, through the Corps of Engineers, to conduct safety inspections of non-Federal dams throughout the United States. Pursuant to that authority, the Chief of Engineers issued "Recommended Guidelines for Safety Inspection of Dams" in Appendix D, Volume 1 of the U.S. Army Corps of Engineers' Report to the United States Congress on "National Program of Inspection of Dams" in May, 1975.

The recommended guidelines were prepared with the help of engineers and scientists highly experienced in dam safety from many Federal and state agencies, professional engineering organizations and private engineering consulting firms. Consequently, the evaluation criteria presented in the guidelines represent the comprehensive consensus of the engineering community.

Where necessary, the guidelines recommend a two-phased study procedure for investigating and evaluating existing dam conditions so deficiencies and hazardous conditions can be readily identified and corrected. The Phase I study is:

(1) a limited investigation to assess the general safety condition of the dam

(2) based upon an evaluation of the available data and a visual inspection

(3) performed to determine if any needed emergency measures and/or if additional studies, investigations, and analyses are necessary or warranted

(4) not intended to include extensive explorations or analysis, nor to provide detailed alternative correction recommendations

The Phase II investigation includes all additional studies necessary to evaluate the safety of the dam. Included in Phase II, as required, should be additional visual inspections, measurements, foundation exploration and testing, material testing, hydraulic and hydrologic analyses and structural stability analyses.

The authority for the Corps of Engineers to participate in the inspection of non-federally owned dams is limited to Phase I investigations with the exception of situations of extreme emergency. In these cases the Corps may proceed with Phase II studies but only to the extent needed to answer serious questions relating to dam safety that cannot be answered otherwise. The two phases of investigations outlined above are intended only to evaluate project safety and do not encompass in scope the engineering required to perform design or corrective modification work. Recommendations contained in this report may be for either Phase II safety analyses or detailed design study for corrective work.

The responsibility for implementation of these Phase I recommendations rests with the dam owner and the State of Montana. It should be noted that nothing contained in the National Dam Inspection Act, and no action or failure to act under this act shall be construed (1) to create liability in the United States or its officers or employees for the recovery of damage caused by such action or failure to act or (2) to relieve an owner or operator of a dam of the legal duties, obligations, or liabilities incident to the ownership or operation of the dam.

1.1.2 Purpose

The purpose of the inspection and evaluation is to identify conditions that threaten public safety, so that they may be corrected in a timely manner by non-Federal interests.

1.1.3 Inspection

The findings and recommendations in this report were based on an June 8, 1979, visual inspection of the project, a detailed review of available plans and specifications, and design analyses. Inspection procedures and criteria were those established by the Recommended Guidelines for Safety Inspection of Dams (Ref. 1).

Personnel present during the inspection included:

Arthur Van't Hul, City Engineer, Bozeman, Montana

Larry Tegg, Engineer, State of Montana, Department of Natural Resources and Conservation

Robert Clark, Engineer, State of Montana, Department of Natural Resources and Conservation

Jack Nash, President, Bozeman Creek Reservoir Association (B.C.R.A.)

Kenny Kraft, B.C.R.A.

Bill Hoffman, B.C.R.A.

A. J. Goldstein, Secretary, B.C.R.A.

Orville W. Bridgewater, Operator, City of Bozeman

Don Strung, Employee, City of Bozeman

Rick Eckerlin, Geologist, Corps of Engineers

CH2M HILL personnel who participated in the field inspection and contributed to this report are:

Miles C. Bubenik, Geotechnical Engineer, Team Leader

Jerry Jacksha, Geotechnical Engineer

Loren Bottorff, Hydrologist/Hydraulics Engineer

1.2 DESCRIPTION OF PROJECT

1.2.1 General

Mystic Reservoir and Dam (see Photos 1 and 3) are located on Bozeman Creek, in Gallatin County, Montana, approximately 12 miles southeast of the City of Bozeman (see Plate 1). The dam is currently listed as having high downstream hazard potential; its Federal identification number is MT-880. The 48-foot-high earth dam was constructed in 1904 and it impounds 1,520 acre-feet at dam crest, elevation 6401.9 feet NGVD. Based on a visual field reconnaissance and engineering judgment, the dam is located such that its failure has the potential to endanger lives and cause property damage in the City of Bozeman and agricultural lands downstream of the dam. On the basis of this information and in accordance with the recommended guidelines, the project size is intermediate and the downstream hazard potential is high (Category 1).

The 57.1-acre reservoir, used for water supply and irrigation storage, is owned by the City of Bozeman and the Bozeman Creek Reservoir Association.

1.2.2 Regional Geology Seismicity

The information in paragraphs 1.2.2 and 1.2.3 was obtained from a memorandum by R. D. Eckerlin (Ref. 5).

> Mystic Lake Dam is located on Bozeman Creek (formerly Sourdough Creek) in the Gallatin Range within the Northern Rocky Mountains physiographic province. The Gallatin Range forms the divide between the Gallatin River Valley on the west and the Yellowstone River Valley on the east. At the project, Bozeman Creek flows through a narrow valley cut in rock. The structural evolution of this region is characterized by tectonic movement of considerable magnitude. Northwest and northeast trending folds and thrust faults dominated the late Cretaceous (Laramide Orogeny). Most block and normal faulting occurred in the middle to late Tertiary Period; however, some normal faults have been recently active as seen in the Hebgen Lake area in the southern part of the Madison Range. Several north to northwest trending faults lie within 2-1/2 miles of the dam. The area has been subjected to mass gravity movement, including debris slides, slumps, rockslides, and earth-flows. Sliding in the northern Gallatin Range appears to have resulted from significant valley glaciation causing oversteepened valley slopes coupled with the structural complexity and steeply dipping bedding planes of the Paleozoic and Mesozoic rocks in the area. Tectonic movement may also have been a major contributing factor to sliding since the region has been seismically active. The southern and eastern shorelines of Mystic Lake consist of a very large Holocene landslide consisting of unstratified heterogeneous mixtures of soil and angular rock fragments principally of volcanic origin. This slide apparently blocked Bozeman Creek, forming a natural dam which created Mystic Lake. The slide mass extends about 600 feet downstream from Mystic Lake Dam.

The dam lies in a zone that is susceptible to major earthquake damage. Algermissen and Perkins (Ref. 6) indicate this zone could expect a maximum Modified Mercalli intensity X event, or an equivalent 7.3 event, in the next 100 years. An estimated probability of 0.4g horizontal bedrock acceleration has a 90 percent chance of not being exceeded in 50 years. It is estimated that the dam experienced a greater than 0.2g bedrock acceleration during the 1959 Hebgen Lake earthquake.

1.2.3 Site Geology

Mystic Lake Dam is founded in part on landslide debris and on Paleozoic bedrock. The right abutment, together with the right side of the dam, is founded on bedrock units of the Quadrant and Amsden formations. Bedding strikes from N10°W to 54°W and dips 36° to 62° northeast. Northern Testing Labs (NTL) drilled several borings through the crest of the dam into the bedrock foundation. These borings indicate that the right side of the dam is founded on fractured, weathered, and decomposed quartzite and quartzose sandstone, units of the Quadrant Formation. In local areas at the foundation-embankment contact, these rocks have completely decomposed to a very permeable medium-grained quartzose sand. Other bedrock comprising the foundation underlying the right side consists of weathered and fractured dolomite, calcareous sandstone, and siltstone units of the Amsden Formation. The left half (east side) of the embankment is founded on the toe of a recent age landslide which also forms the entire east shoreline of Mystic Lake. The slide is composed of volcanic rubble which includes andesite, basalt, breccia, tuff, and conglomerate.

1.2.4 Design and Construction History

The design and construction history of Mystic Lake Dam has been summarized by the City Engineer for Bozeman, Montana, Arthur Van't Hul, and was transmitted to the Forest Supervisor, U.S. Forest Service, Gallatin National Forest. It is included as Appendix I.

CHAPTER 2

INSPECTION AND RECORDS EVALUATION

2.1 HYDRAULICS AND STRUCTURES

2.1.1 Spillway

The uncontrolled chute spillway for Mystic Lake Dam is located near the right abutment of the dam. The chute follows the downstream slope of the dam to a stilling basin at the dam toe (Plate 2 and Photos 1, 2, and 4). The spillway was built in about 1959 and replaced an old spillway that had served the dam since 1916. The spillway is crossed by a free span bridge.

The spillway structure begins at the upstream face of the dam with 40-foot-wide concrete apron at elevation 6395.2 feet NGVD (6.7 feet below low point on the dam). Wing walls, beginning at the 40-foot-wide section, converge in a distance of 10 feet to form the 20-foot-wide spillway crest. The spillway crest is at elevation 6396.2 feet NGVD (5.7 feet below low point on the dam). From the crest, the chute narrows uniformly in a distance of 50 feet from the 20-foot width to a 10-foot width. The slope of the invert of the chute gradually increases from flat at the 20-foot-wide section to 1 V on 2 H at the beginning of the 10-foot-wide section. The 10-foot-wide chute continues at this slope for 41 feet. The slope gradually flattens to form the stilling basin portion of the structure. The stilling basin is about 55 feet long with 3-foot-high side walls. The discharge from the low-level outlet (Paragraph 2.1.2) enters the stilling basin at 18 degrees from parallel with the spillway (Photo 8).

A log boom is located directly upstream from the spillway entrance but some debris was noted in the spillway chute. The boom appears to be anchored too close to the spillway entrance, where high velocity flows may prevent efficient trapping of debris. The spillway concrete appeared to be in good condition. However, a large crack was noted near the end of the spillway stilling basin where some undermining may have occurred (see paragraph 3, letter from City of Bozeman dated December 3, 1979, attached at back of this report). Water at the end of the stilling basin prevented inspection. This crack may be the one that initiated maintenance work in 1976 (see Appendix I). No further damage was observed during the inspection, and the crack is in a location that does not endanger the structure.

The spillway discharge rating was developed by assuming control occurs at an 18.5-foot-wide section of the chute just downstream of the spillway crest. The invert of the 18.5-foot-wide section is at the same elevation as the 20-foot-wide spillway crest section. Critical depth was calculated for various flows to determine the rating. The maximum discharge capacity of the spillway with the reservoir at the top of dam, elevation 6401.9 feet NGVD, was estimated to be 780 c.f.s. The spillway rating curve is presented on Plate 3. The chute walls are of adequate height to contain the 780 c.f.s., but the stilling basin walls will be overtopped by tailwater or the hydraulic jump. Some damage may occur to the stilling basin concrete, causing backcutting into the embankment.

2.1.2 Outlet

The outlet works for Mystic Lake Dam is located about 100 feet from the right abutment (Photo 1). The two conduits (12-inch-diameter and 16-inch-diameter bell mouth cast iron pipe) extend through the embankment (Plate 6) to an energy dissipating structure (Plate 5). The intake structure could not be inspected because it was below reservoir water level. The conduits could not be visually examined at the time of the inspection because of their small diameter. According to Mr. Van't Hul, the dam was originally equipped with a gate tower at the upstream end of the outlet conduits. In 1964 the tower was removed and the intake structure was modified so the flow in two conduits could be controlled by a single 24-inch by 24-inch slide gate. The gate stem follows the upstream face of the dam and the gate wheel is located in a shack at the crest of the dam. The conduits extend approximately 175 feet from the intake to the outlet structure. The outlet structure is a box with an end wall that creates a tailwater to submerge the conduits. A portion of the structure is covered and contains a vent pipe (Plate 5). Seepage (approximately 80 gallons per minute) from near the base of the vent pipe did not diminish when the outlet gate was closed, indicating that the seepage was through the embankment. This seepage may be flowing along the outside of the outlet conduits. A parshall flume is located just downstream of the outlet structure. The discharge from the outlet works merges into the spillway stilling basin just downstream of the flume (Photo 8).

The two conduits were inspected by television camera in 1977. The conduit inspections were performed after a sink hole developed in the dam in July, 1977 (see Appendix II). The first inspection revealed that the 12-inch-diameter pipe had a vertical displacement of 3 inches at the upstream face of the core wall, with the upstream section of pipe lower

than the downstream section of pipe. The inspection also revealed sections with considerable corrosion and out-of-round sections. Dye injected to the upstream sink area appeared in the discharge from the 12-inch-diameter conduit (see Appendix II). Television inspection of the 16-inch-diameter conduit indicated that it was intact but contained some out-of-round areas. In order to prevent particle migration, the development of additional sink holes, and possible dam failure, mechanical expanding plugs were subsequently placed in the upstream and downstream ends of the 12-inch-diameter conduit as a temporary measure until repairs could be made.

In 1978 the two conduits were again inspected by television camera to determine if any changes had occurred since the previous year. The 16-inch-diameter conduit showed some change in the form of standing water, indicating additional settlement. This continued settlement indicates that additional breaks and/or separation of the conduits at the joints will occur. The City of Bozeman has plans to place liners in the conduits but this may not prevent future breaks. The two conduits have been in service for approximately 75 years, which may be beyond the expected useful life for bell mouth cast iron pipe.

The rating of the 16-inch-diameter outlet conduit was developed with the gate fully open. A Mannings "n" of 0.016 was used to estimate friction losses with the conduit flowing full. The maximum discharge capacity of the outlet works, with the reservoir at top of dam, elevation 6401.9 feet NGVD, was estimated to be 25 c.f.s.

2.1.3 Freeboard

Because the dam overtops during the PMF (see section 2.2.4) it has no freeboard. The vertical distance between the low point on the dam and the reservoir level at the time of the inspection was 14.2 feet. The spillway is 5.7 feet below the low point on the crest of the dam. The crest of the dam varies 0.5 feet in elevation over its 440-foot length. The effective fetch for wind-generated waves is about 0.3 miles and wave runup on the embankment is estimated to be about 3 feet. Although the dam will overtop during the PMF, the vertical distance between the crest of the dam and the normal reservoir level is adequate to prevent overtopping the embankment by wind waves.

2.2 HYDROLOGY, CLIMATOLOGY, AND PHYSIOGRAPHY

2.2.1 General

The climate of the area is continental in nature characterized by warm summers and cold winters. The nearest climatological station (elevation 4856 feet NGVD) is at Bozeman at Montana State University, about 11 miles northeast of the Mystic Lake drainage basin. Mean annual precipitation at the station is 18.7 inches with 48 percent falling in April through July. Mean February precipitation is 0.65 inches and mean June precipitation is 3.22 inches. Mean annual precipitation on the Mystic Lake drainage basin is probably near 30 inches. Mean annual temperature at Bozeman is 43.1 degrees Fahrenheit (F); mean January temperature is 20.8 degrees F; and mean July temperature is 66.4 degrees F. Temperatures on the Mystic Lake Dam drainage basin probably average about 10 degrees cooler than Bozeman. Summer temperatures can exceed 100 degrees F and winter temperatures can dip well below 0 degrees F. Winters have few extended cold spells because of frequent warm, windy, "chinook" periods.

The drainage basin area for Mystic Lake Dam is 5.3 square miles. The basin elevations range from 6400 feet NGVD at the dam to 9000 feet NGVD on the southeastern boundary. The basin is heavily forested. The lake is supplied by several small inflow streams.

2.2.2 Reservoir Storage and Spillway Discharge

The reservoir has a surface area of 57.1 acres and a storage of 1190 acre-feet at spillway crest, elevation 6396.2 feet NGVD. Approximately 330 acre-feet of surcharge storage is available in the reservoir between the spillway crest and the dam crest. The spillway discharge with the reservoir at the dam crest is 730 c.f.s., about 64 acre-feet per hour.

2.2.3 Estimated Probable Maximum Flood

The probable maximum flood (PMF) is the flood expected from the most severe combination of critical meteorologic and hydrologic conditions that are reasonably possible in the region. An estimate of the PMF was made during this dam safety analysis and was routed through the reservoir.

The procedure contained in U.S. Weather Bureau's Technical Paper 38 (Ref. 2) was used to compute the probable maximum precipitation (PMP). This storm, for the 5.3-square-mile basin, produces 11.8 inches in 6 hours and 15.7 inches in 24 hours. The 72-hour precipitation was estimated to be 115

percent of the 24-hour precipitation value, which is 18.1 inches.

As an alternative to computing snowmelt and assigning an infiltration rate, a ground condition with no infiltration losses was assumed during the entire flood. This is possible because minimum infiltration losses during snowmelt are approximately offset by the melt. A base flow of 80 c.f.s. was also used for the entire flood.

A triangular unit hydrograph for a 10-minute rainfall duration was developed for the 5.3-square-mile drainage basin by procedures outlined in Design of Small Dams (Ref. 3). A curvilinear fit of the triangular unit hydrograph was used. The PMP was applied to the unit hydrograph by means of the computer program, HEC-1 (Ref. 4). This estimate of the PMP produced a flood with a peak flow of 36,800 c.f.s. and a volume of 5,600 acre-feet.

2.2.4 Flood Routing

The PMF was routed through the reservoir by using the computer program HEC-1 (Ref. 4). The reservoir level was assumed to be at the spillway crest at the beginning of the PMF and the outlet works to be fully open during the entire PMF. The routing shows that the dam will be overtopped during the PMF when approximately 23 percent of the total flood volume enters the reservoir. Floods much smaller than the PMF will overtop and possibly cause the dam to fail.

2.3 GEOTECHNICAL EVALUATION

2.3.1 Dam Embankment

Initial water impoundment behind the 48-foot-high earth dam was in 1904. The dam has a 15-foot crest width and is 440 feet long. Both upstream and downstream slopes are about 1 V on 2 H. (see Plate 6). Plans show a masonry core wall located beneath the upstream embankment shoulder (Plate 5) and the core wall extends from near original ground to within 7 feet of the dam crest. The core wall is 4 feet wide at its base and 2 feet wide at the top. The core wall is founded on rock at the right abutment and river alluvium and slide debris to about station 1+40, as shown on Plate 7. The dam foundation from the left abutment to at least the outlet conduits is slide debris. Slide debris consists of boulders, gravels, sand, and silts. The right abutment consists of deeply weathered and permeable bedrock.

Explorations were performed by Northern Testing Laboratories, Inc., in September, 1977, to investigate a sink hole and

identified embankment materials as clays, silts, sands, and gravels (Appendix II).

This dam does not incorporate an internal drain in either the deep section near the right abutment or the section founded on slide debris near the left abutment. A profile of the dam is shown on Plate 7 and a typical embankment section on Plate 6.

The two low-level conduits, one 12-inch-diameter bell mouth cast iron and one 16-inch-diameter bell mouth cast iron, were inspected by television camera in 1977 and again in 1978. The inspection showed that both conduits had significant settlement. The 12-inch conduit had a 60-foot length downstream of the masonry core wall that had at least a 4- to 6-inch settlement, and, at a point just upstream of the core wall, the conduit had an abrupt 3-inch vertical displacement. The 16-inch conduit also showed a 4- to 6-inch settlement in a 40-foot length immediately upstream of the masonry core wall. As the conduits were probably constructed to some downstream slope, the observed settlement is probably only a fraction of the total that may have occurred. The conduit settlement may be the result of embankment settlement following the 1959 Hegben earthquake, which had an estimated acceleration of more than 0.20 at the dam. Project records also show that the dam was raised about 2 feet in 1959; however, it is not stated whether or not the raise was the result of subsidence caused by the earthquake. The conduit settlement may also be related to seepage and loss of material adjacent to both conduits.

It seems reasonable to assume that earthquake activity in this area will continue and further adjustments in the dam section will occur.

Original riprap on the upstream face extends to about the invert elevation of the present spillway (see Photo 3). Riprap above this elevation includes rock and concrete and is adequate protection for waves generated in the short fetch.

2.3.2 Foundation Conditions, Seepage, and Drainage

As stated in Section 1.2.3 Site Geology, and in the preceding paragraph, the right abutment bedrock is deeply weathered and is permeable. The left embankment is founded on slide debris.

The left side embankment, as seen in Photos 5 and 6, is constructed across a depression in the slide debris, and seepage waters collect adjacent the downstream toe. The

high water mark in the area suggests the water ponds to a depth of about 6 or 7 feet. Erosion adjacent the toe suggests the foundation materials, which are slide debris, may be the source of this seepage. The differential head (reservoir and high water mark) with the reservoir at spillway crest is about 10 feet. Considerable seepage, estimated to be about 80 g.p.m., was observed during this inspection, emerging adjacent the downstream low-level conduit discharge with the 16-inch gate partially open.

No change in seepage quantity was noted with the upstream slide gate in the closed position. No other seepage was noted.

Observations on seepage are noted in a report dated August 8, 1977, by Mr. Theodore Williams, P.E., which is attached as Appendix III to this report. Williams' report notes water entering the upstream face of the dam near elevation 90.2 to 90.7 (local datum). Water entrance was associated with a loud roaring sound from the dam's interior, and muddy water was observed to exit about 300 feet downstream of the dam in a channel rapids. The water intake, roaring noise, and exit water diminished with lowering the pool and ended when the pool reached a certain level. Also, flow in Bozeman Creek downstream of the dam was reduced by more than 3 c.f.s. with lowered pool. Results of explorations and seepage investigations conducted by Northern Testing Laboratories, Inc., to investigate a sink hole in the dam near the right abutment are presented in Appendix II.

The sink hole was interpreted by Northern Testing Laboratories, Inc., as having resulted from materials piping into a breach in the 12-inch-diameter cast iron conduit. The sink hole was excavated to a depth of about 20 feet; a filter was constructed, and the excavation was backfilled and compacted with impervious materials. The 12-inch conduit was temporarily plugged until plans for repair could be developed. Northern Testing Laboratories, Inc., recommended lining the outlet pipes, grouting the liners, and placing a grout curtain along the upstream face of the core wall.

The City of Bozeman plans to rehabilitate both the 12-inch and 16-inch conduits and grout the voids adjacent to the conduits. This work was not done at the time of inspection.

There are no piezometers installed in the dam or slide area except for two placed in drill holes by Northern Testing Laboratories, Inc.

2.3.3 Stability

In studying available information, we recognize that the dam has withstood severe seismic loads in its 75-year history; however, the reservoir levels at the time of these past events are unknown, and we have no assurance that the dam has experienced the most severe seismic loading to be anticipated. We also believe the dam has and, without corrective measures, will continue to have serious problems with seepage and the low-level outlet conduits, which could lead to failure of the dam.

In addition, the internal piezometric conditions and stability of the downstream slope and foundation are not known. A seepage pond adjacent the left abutment tends to raise the phreatic surface in the slide mass and could lead to instability of the old slide, resulting in dam failure. At present, insufficient information is available to assess overall stability.

2.4 PROJECT OPERATIONS AND MAINTENANCE

The facility is owned jointly by the City of Bozeman and the Bozeman Creek Reservoir Association. The City of Bozeman is responsible for operations and maintenance of Mystic Lake Dam, but the Bozeman Creek Reservoir Association retains voting control of the facility. Information on operations and maintenance was obtained from discussions with Mr. Van't Hul as a formal operation and maintenance program for the dam does not exist.

2.4.1 Dam

Maintenance of the dam is performed as required. The embankment was free from brush and trees and appeared to be well maintained. The City of Bozeman performed considerable work at the dam when a sink hole was detected in 1977. The City of Bozeman and the U.S. Forest Service perform inspections of the facility at about 3-year intervals.

2.4.2 Reservoir

The dam operator, from the City of Bozeman, visits the dam as soon as allowed by spring thaw. He then visits the dam weekly until the reservoir is nearly full, three times a week when full, and daily when the reservoir is spilling. In addition, weekly visits are made by the Bozeman City Engineer during periods of high runoff. Water is released through the low-level outlet as needed to supplement stream flows for irrigation and for Bozeman's water supply. According to Mr. Van't Hul, Mystic Lake presently supplies only a

small portion of the water used by the city. However, as the city grows, it will have to rely more on Mystic Lake to supply water needs.

Since detection of the sink hole in 1977, the U.S. Forest Service has required that the 12-inch-diameter conduit remain plugged until repaired. They also require the 16-inch-diameter conduit to remain open during the winter until much of the basin snow has melted. At that time the outlet is partly shut and the reservoir level is brought up to about 6 feet below spillway crest. This is only a temporary procedure until repairs are made to the 12-inch-diameter conduit.

2.4.3 Warning System

The City of Bozeman has developed an emergency plan for use in the event of failure or potential failure of Mystic Lake Dam. The plan identifies action to be taken under four categories of failure. Under signs of a possible failure, such as noticeable settlement or noticeable change in seepage through the dam, the reservoir attendant shall notify the Bozeman City Engineer who will take appropriate action. Under signs of a slowly developing failure, when signs of distress are increasing at a noticeable rate or the operator has concerns that failure is developing, the reservoir attendant shall notify the Bozeman City Engineer who will notify the City Manager and the Forest Ranger of the Gallatin National Forest. The City Engineer will also alert Toston Dam and Canyon Ferry Dam to request that appropriate action be taken. Under signs of rapidly developing failure, when the operator feels there is no question but that dam failure is imminent, the attendant will notify the City Engineer. The City Engineer will notify the Bozeman City Manager, the U.S. Forest Service, Toston and Canyon Ferry Dams, and the sheriff's office, Civil Defense, radio stations, and television stations in Gallatin and Broadwater Counties. The City Engineer or the City Manager will notify the Department of Civil Defense and the Governor's Office if it appears that the National Guard may be needed. In the event of a catastrophic failure, such as one due to an earthquake or sabotage, the same course of action as under a rapidly developing failure will be taken. This plan does identify the "chain of command" and action to be taken once a potential failure is identified. The planned procedure for warning possibly affected downstream development should be tested. However, the plan does not make adequate provision for dam overtopping caused by a short intense storm when a failure may go undetected until downstream damage occurs, since the dam does not have a full-time attendant. A remote sensing system for reservoir level and rate of change of reservoir level may alleviate this problem.

CHAPTER 3

FINDINGS AND RECOMMENDATIONS

3.1 FINDINGS

Visual inspection of the dam, supplemented by analysis of the project in terms of the recommended guidelines performance standards, resulted in the following findings.

3.1.1 Size, Hazard Potential, and Safety Evaluation

The 48-foot-high Mystic Lake Dam impounds 1,520 acre-feet of water with the reservoir at the crest of the dam. Based on our visual assessment, a failure of the dam would cause flooding, extensive property damage, and possible loss of life. On the basis of this assessment, and in accordance with the recommended guidelines (Ref. 1), the project is intermediate in size and has a high (Category 1) downstream hazard potential. The recommended spillway design flood for this project is the full PMF. Because the project can safely handle only 23 percent of the PMF, without overtopping and causing failure of the dam, Mystic Lake Dam is considered unsafe until the recommended actions are complete. In addition, known seepage conditions and problems with the outlet conduit are in need of immediate correction and numerous seepage and stability questions remain unanswered and are in need of attention.

3.1.2 Embankment Dam

The dam embankment has withstood severe seismic shock in its 75-year life; however, the coincident reservoir conditions are unknown. The unknown seepage and foundation conditions, condition of the core wall, and stability of the left abutment slide are of concern and need further detailed engineering investigation and correction as required. While past reported seepage adjacent to a portion of the left embankment section was not flowing at the time of this inspection, evidence suggested the seepage creates a pond to a depth of about 6 or 7 feet. This pond raises the phreatic surface in the slide debris and may contribute to instability of the slide mass upon which the dam is partially founded.

3.1.3 Spillway and Reservoir Capacity

The reservoir has a surface area of 57.1 acres and a storage of 1,190 acre-feet at spillway crest, elevation 6396.2 feet NGVD. Approximately 330 acre-feet of surcharge storage are available in the reservoir between spillway crest and dam

crest. The discharge of the spillway, with the reservoir at the dam crest, is 780 c.f.s. Inspection guidelines (Ref. 1) recommend that a dam of intermediate size and high downstream hazard potential be capable of safely handling the PMF. An estimate of the PMF indicates that the dam will be overtopped during the PMF when 23 percent of the total flood volume enters the reservoir. The dam will overtop and fail during floods much smaller than the PMF.

3.1.4 Outlet Works

A sink hole was detected in the dam in July 1977 and was traced to a break in the 12-inch-diameter outlet conduit. The conduit was subsequently plugged with mechanical expanding plugs as a temporary measure until repairs are made. The 12-inch-diameter and the 16-inch-diameter conduits were inspected by TV camera in 1977 and again in 1978. The inspection found corrosion, out-of-round lengths of conduit, settlement, and separation of pipe joints. Also, the inspections found that additional settlement of the 16-inch-diameter conduit had occurred during the year. The continued settlement indicates that material is being removed from the zone adjacent the conduit and additional breaks in the conduits are likely. Seepage, which we observed on day of inspection emerging from the embankment at the base of the outlet structure, may be flowing along the outside of the conduits. Northern Testing Laboratories, Inc., (Appendix II) recommended lining both outlet pipes, grouting the liners and the sink hole, and placing a grout curtain along the upstream face of the masonry corewall. If seepage is indeed flowing outside of the conduits, it is our opinion that the lining of the conduits will be of little value unless the external seepage is stopped, because settlement will continue and additional breaks in the conduits are likely.

3.1.5 Operations and Maintenance

The facility is owned jointly by the City of Bozeman and the Bozeman Creek Reservoir Association. The City of Bozeman is responsible for operations and maintenance. Maintenance of the dam is performed as required. Since the leak was detected in the dam in 1977, the U.S. Forest Service has required that the 12-inch-diameter conduit remain plugged with mechanical expanding plugs until repairs are made. They also require the 16-inch-diameter conduit to remain open during the winter until much of the basin snow has melted. At that time, the outlet is partly shut and the reservoir level is brought up to about 6 feet below spillway crest. This is only a temporary procedure until repairs are made to the 12-inch-diameter conduit. The City of Bozeman and the U.S. Forest Service perform inspections of the facility at about 3-year intervals. The City of Bozeman has developed an

emergency plan for use in the event of failure or potential failure of Mystic Lake Dam. However, the plan does not make adequate provision for dam overtopping caused by a short intense storm when a failure may go undetected until downstream damage occurs because the dam does not have a full-time attendant.

3.2 RECOMMENDATIONS

The findings suggest that high priority be given the following recommendations:

1. Immediately improve, update, and periodically test the existing emergency warning plan.

2. Provide drainage to eliminate ponded seepage water on left abutment.

3. Provide survey monuments on dam and left abutment slide and monitor long-term movement.

4. Immediately rehabilitate or replace the outlet conduits. The rehabilitation or replacement must consider the deteriorated condition of existing conduits, including: corrosion, deformed conduit sections, continuing settlement of the conduits, possible voids adjacent the conduits, and the potential for major damage due to earthquakes.

5. Immediately take the necessary actions to eliminate all known seepage conditions.

6. Inspect the area downstream from stilling basin and repair if basin undercutting or erosion has occurred. As an interim measure, prior to permanent project modification, provide protection around the stilling basin to minimize potential for damage to embankment resulting from flow overtopping basin walls.

7. Conduct advanced engineering studies to:

   - Determine the PMF

   - Conduct and place on file, stability and additional seepage analyses of the dam and left bank slide area. We recommend these analyses be performed by qualified geotechnical engineers and be based on: seismic and static loading conditions; in situ strength properties of the embankment, foundation, and abutment materials; and phreatic surface

conditions. Determine the seismic loads based on a seismic assessment of the area, and also evaluate the project's response to a seismic event. Establish the material strength properties by drilling and sampling with laboratory testing as appropriate; and obtain the phreatic surface by installing and monitoring piezometers in the dam, the left abutment slide area, and in the area between the dam and reported seepage exit area. Perform additional seepage study by observing piezometer levels, downstream flow, exit areas, and total downstream flow for various pool elevations to determine magnitude and severity of the seepage problem. Maintain complete records of all observations to establish trends and for use by inspecting parties.

- Perform a hydraulic routing of a dam breach hydrograph to more accurately establish the downstream hazard potential and effects of dam failure.

8. Modify the project, as studies indicate, to safely handle either the PMF or the inspection guidelines recommended spillway design flood, as determined by the dam breach flood routing, with assured stability.

9. Conduct periodic inspections of the project by engineers experienced in dam design and construction. Time intervals between inspections need to be established by the inspecting engineer but not to exceed 5-year intervals.

10. If the above recommendations are not accomplished in a timely manner, we recommend consideration be given to removing the dam.

REFERENCES

1. U.S. Army Corps of Engineers, Office of the Chief of Engineers Report to the U.S. Congress, National Program of Inspection of Dams, Vol. 1, Appendix D, "Recommended Guidelines for Safety Inspection of Dams," Washington, D.C., Department of the Army, May 1975.

2. U.S. Weather Bureau, Technical Paper 38, Generalized Estimates of Probable Maximum Precipitation for the United States West of the 105th Meridian, Washington, D.C., 1960.

3. U.S. Bureau of Reclamation, "Design of Small Dams," 2nd Edition, 1974.

4. U.S. Army Corps of Engineers, Hydrologic Engineering Center, HEC-1 Flood Hydrograph Package, Davis, California, January 1973.

5. R. D. Eckerlin, U.S. Army Corps of Engineers geologist, Memorandum on Mystic Lake Dam Inspection, July 1979.

6. S. T. Algermissen and D. M. Perkins, "A Probabilistic Estimate of Maximum Accelerations in Rock in the Contiguous United States," Bulletin, U.S. Department of the Interior, Open file report, U.S. Geological Survey, No. 76-416, 1976.

APPENDIX 1

MYSTIC LAKE

Location:

Mystic Lake is located in Lots 1, 2, 3 and 4 of Section 30, Township 3 South, Range 7 East, and in the Southeast one-quarter of the Southeast One-quarter of Section 25, Township 3 South, Range 6 East. Information on the original print of the dam construction discloses that only a small portion (the outlet) of the original lake of approximately 15.8 acres in area lies in the extreme east one-half of the Southeast one-quarter of the Southeast one-quarter of Section 25, Township 3 South, Range 6 East; the greater portion of the original lake lying in Lots 3 and 4 of Section 30, Township 3 South, Range 7 East.

Area:

A contour traverse fifteen (15) feet above the level of the original lake encloses an area of thirty-eight and eighteen hundredths (38.18) acres, and a contour traverse thirty (30) feet above the original lake level encompasses an area of fifty-six and sixty-two hundredths (56.62) acres. The breakdown of the reservoir area at the thirty foot level above the original lake is as follows: SE¼, SE¼, Section 25, One (1.0) acre; Lot One (1), Section 30, eleven and six hundredths (11.06) acres; Lot two (2), Section 30, thirteen and seven hundredths (13.07) acres; Lot Three (3), Section 30, seventeen and five tenths (17.50) acres; Lot Four (4), Section 30, fourteen and one-tenth (14.10) acres.

Drainage Area:

The elevation of Mystic Lake is about 7600 feet above sea level.
The drainage area is approximately 6.4 square miles and reaches an elevation of about 8500 feet above sea level. The peak run-off occurs as the result of melting snow. There is very little information available on stream flow at that elevation, but using a high water mark of June, 1932, and a spillway flow of 106 second feet gives a run-off factor of 16.6 second feet per square mile.

Dam:

According to Mr. Ancel Portnell (Water Master for the Bozeman Creek Reservoir Company and the City of Bozeman) construction of a small dam across the outlet of Mystic Lake had not been started some time before the Bozeman

Reservoir Company's structure but the construction was closed down due to lack of approval and a permit from the Forest Service. The project was permitted under an easement granted by the Department of Interior under the Act of March 3, 1891 (Sec. 18 to 21), an Act of May 11th, 1898. No stipulation covering Forest Service interests was signed as a prerequisite to granting of the easement.

The records show that the dam was constructed in 1903 and 1904 under the supervision of S. Fortier, C. E.,as Consultant Engineer and C. M. Thorpe as Construction Engineer. The dam was originally constructed as an earth fill 43 feet high measured above the outlet pipes (one of 16" and one of 12" diameter) installed ten (10) feet below the natural surface of the lake. The top width was thirty (30) feet and both the upstream and downstream slopes were 2:1. The plans indicate a rubble masonry core wall approximately four (4) feet thick at the bottom and two (2) feet thick at the top which ended two (2) feet from the top of dam. The upstream face of the dam was rip-rapped. A timber spillway was constructed approximately 100 feet from the southeast end of the dam. In 1919 a new concrete spillway was constructed approximately thirty (30) feet from the northwest end of the dam.

In August of 1932, Mr. F. E. Thieme, Regional Engineer of the Forest Service, together with other Forest Service personnel and Mr. Arnold, then City Manager of Bozeman, made an inspection of the conditions at the dam. It was noted in that report that during the 1932 runoff there was a flow of 2.2 feet in depth in the spillway leaving only a freeboard on the dam of .9 of a foot. According to the report the Reservoir Company had been installing flash boards in the spillway to enlarge the capacity of the dam and this practice was ordered discontinued and the recommendation was made that the crest of the dam be raised to the height of the spillway cover slab. This was done according to information received.

In 1959 the dam was raised approximately two feet in height and a new concrete spillway 185 feet long and 20 feet wide was constructed approximately sixty-four (64) feet distant southeasterly from the northwest end of the dam, a Parshall flume was installed at the end of the outlet pipes.

Theodore T. Williams was the consulting engineer employed by the Bozeman Creek Reservoir Company to design and supervise the above work. Ingolph Johnson was the contractor performing the construction.

During the fall of 1964, a contract was let by the Bozeman Creek Reservoir Company to Wallace Diteman, Inc. Contractors for the purpose of dismantling the old gate structure and installation of a new outlet control in the amount of $5162.63. The work consisted of dismantling the old log crib and catwalk above the outlet valves on the 12 inch and 16 inch outlet pipes, down to the masonry foundation removal of the 12 and 16 inch valves, pouring a concrete interliner and installation of a 24" x 24" slide gate Armco Model 50-10, with a hand wheel on the crest of the dam, cutting a 2 x 4 inlet in the face of the old masonry base, installation of trash racks over the side inlet and top of gate wall. The design for this work was done by the Soil Conservation Service of the Department of Agriculture and the writer, with the writer supervising the construction.

In 1967, some major maintenance work was accomplished on the lower end of the spillway floor, by the City Water Department under the supervision of the City Engineer. A longitudinal crack had developed in the center of the spillway floor slab and several holes had developed by erosion in the slab undoubtedly caused by seepage along the old spillway location. This repair was accomplished by mudjacking with a mixture of masonry cement, washed sand and the addition of a small amount of bentonite for lubrication purposes. Holes were drilled through the slab at several points and the mortar was injected under pressure until it emerged from the holes in the immediate area, the process was then continued to other holes until the flow of water had completely stopped and all cracks were filled by the mortar. The procedure had to be carefully watched in order to keep the pressure from raising the slab and causing further opening of the cracks.

Reservoir Capacity:

The original lake area of 15.8 acres was estimated by C. M. Thorpe to contain about one hundred (100) acre feet in volume, the area encompassed by the fifteen (15) foot contour (38.18 acres) computed at 404.85 acre feet capacity and the volume between the fifteen (15) foot contour and the surface area of the thirty (30) foot contour above the original lake level computed at fifty six and sixty two (56.62) acres being seven hundred eleven (711) acre feet; a total volume of one thousand one hundred and fifteen (1115) acre feet capacity above the original lake level or a grand total of one thousand two hundred fifteen acre feet.

According to the plans on file in the City Engineer's Office, the elevation of the top of dam is 102.2, the floor of the spillway 96.2, the side intake and low end of the slide gate opening 61.5 and the invert of the 16 inch outlet pipe 55.84.

According to the available records the outlet pipes were installed ten (10) feet below the original lake level. This then would set the original lake level at 65.84 elevation. With the opening of the slide gate at elevation 61.50 the approximately 5.66 bottom feet of the original capacity of 100 acre feet or about forty-five (45) acre feet would not be available for use.

This would then reduce the capacity of the original lake water that would be available for use to about fifty-five (55) acre feet and the total capacity at 30 feet above original lake level approximately one thousand one hundred seventy acre feet. Since the original lake level has been established as being elevation 65.84, the elevation of the thirty foot contour would be 95.84. The spillway floor elevation is 96.20, a difference of .36 of a foot, graphically this would net an additional .48 of an acre in area and an additional 20.4 acre feet in volume, making the gross area of Mystic Lake at capacity fifty-seven and one tenth acres and the gross volume capacity approximately 1190.44 acre feet.

Flow Measurements:

In the original survey notes of the Mystic Lake Dam, Mr. Thorpe stated that he made two measurements of the creek flow at the outlet of the lake. On August 25th, 1891, by measuring the cross-section and timing of floats he calculated a flow of 2.46 cubic feet per second. Again on November 26th, 1897, he measured the creek at the same point by the weir method and found it to be two (2) cubic feet per second.

There has been very little information available on flow measurements of Bozeman Creek. During the interval 1937-1947 the Forest Service in conjunction with the Montana State College operated a gauging station approximately one mile above the City of Bozeman water intake, available data from this station is included herein.

In 1967, the Forest Service and the City of Bozeman, reactivated this gauging station. The Forest Service furnishing the recorder and the City of Bozeman doing the maintenance. Flows from the charts were computed by Professor Ted Williams of the State University and are listed in this report. Flow recordings are kept only during nonfreezing weather.

In 1968 Montana State University in conjunction with a Bacteriological Study of Bozeman Creek Watershed installed two Parshall flumes. One flume was installed on the South Fork of Bozeman Creek above the confluence with the main creek the other flume was installed on the main stream, slightly above the City water intake. The University staff have assembled the data on these flows and the information is included in this report.

One must bear in mind that the flow records of the Forest Service Gauging Station and the large Parshall flume immediately above the City Water Intake Structure include the flow of waters released from the Bozeman Creek Reservoir.

Records from the Forest Service Gauging Station reactivated in 1967 show the following minimum and maximum flows in cubic feet per second.

Year	Month	Maximum	Minimum
1967	May	173	-1
1967	June	130	122.5
1967	July	48	31
1967	August	47.5	21.5
1967	September	25	-1
1967	October	36.5	1
1967	November	188.5	7
1968	April (26th on)	77	17.5
1968	May	205	75
1968	June	205	100
1968	July	88	51.5
1968	August	73.5	27
1968	September	51.5	16
1968	October	45.5	27
1968	November	27	21.5

MYSTIC LAKE

FEB. 17, 1978

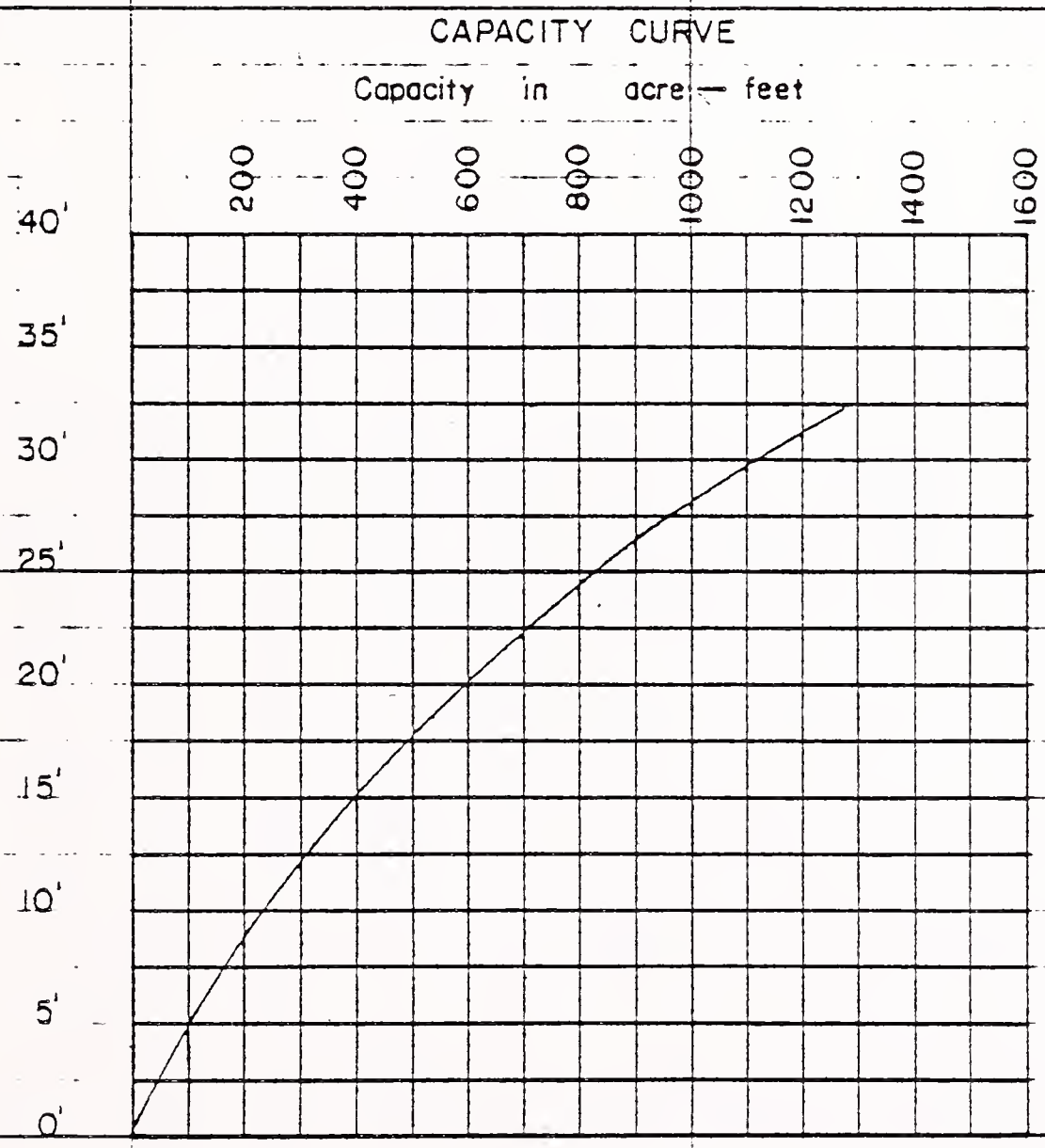


FIGURE 1

MYSTIC LAKE

FEB. 17,. 1978

SPILLWAY DISCHARGE CURVE

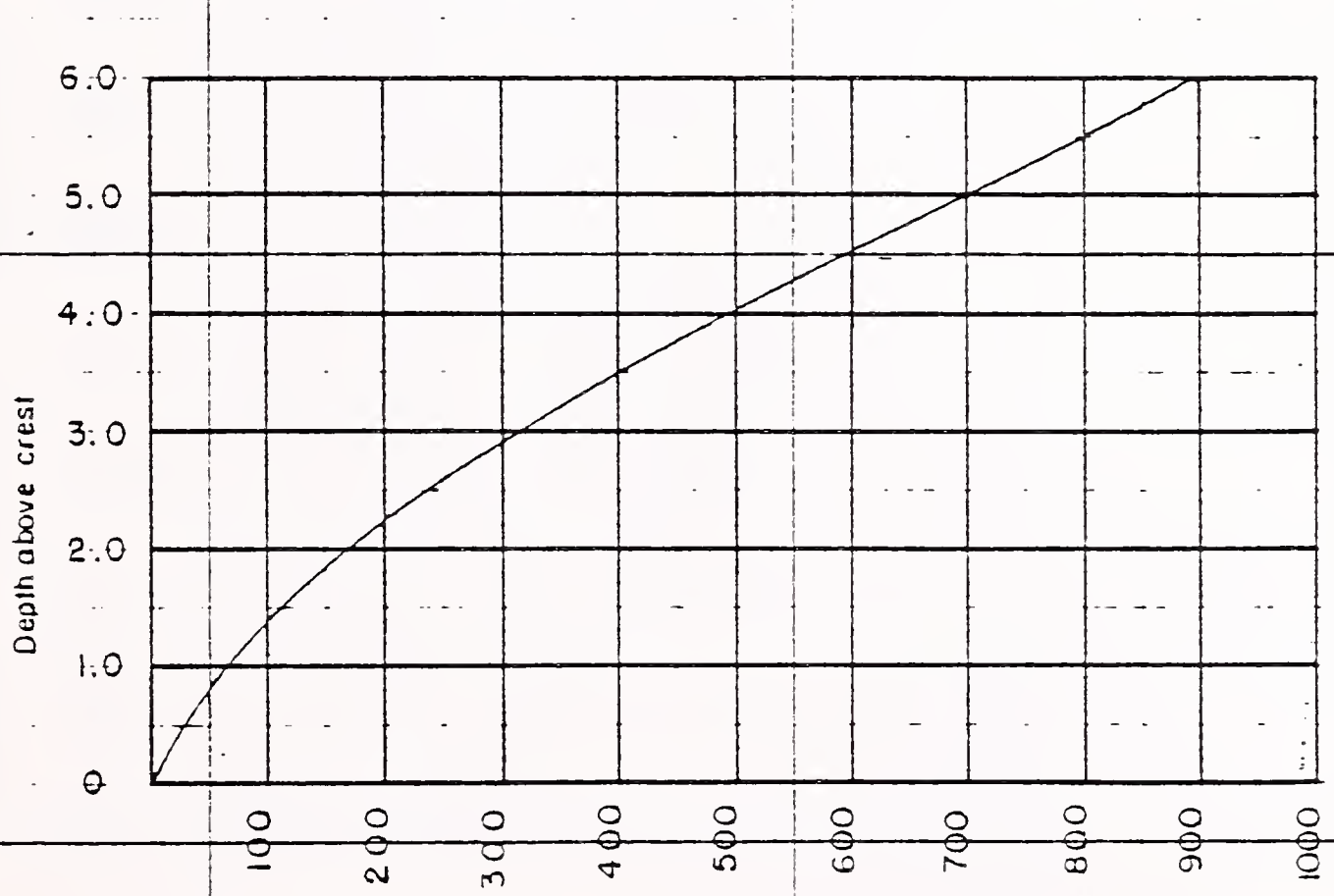


FIGURE 2

MYSTIC LAKE

FEB. 17, 1978

16"- PIPE DISCHARGE CURVE

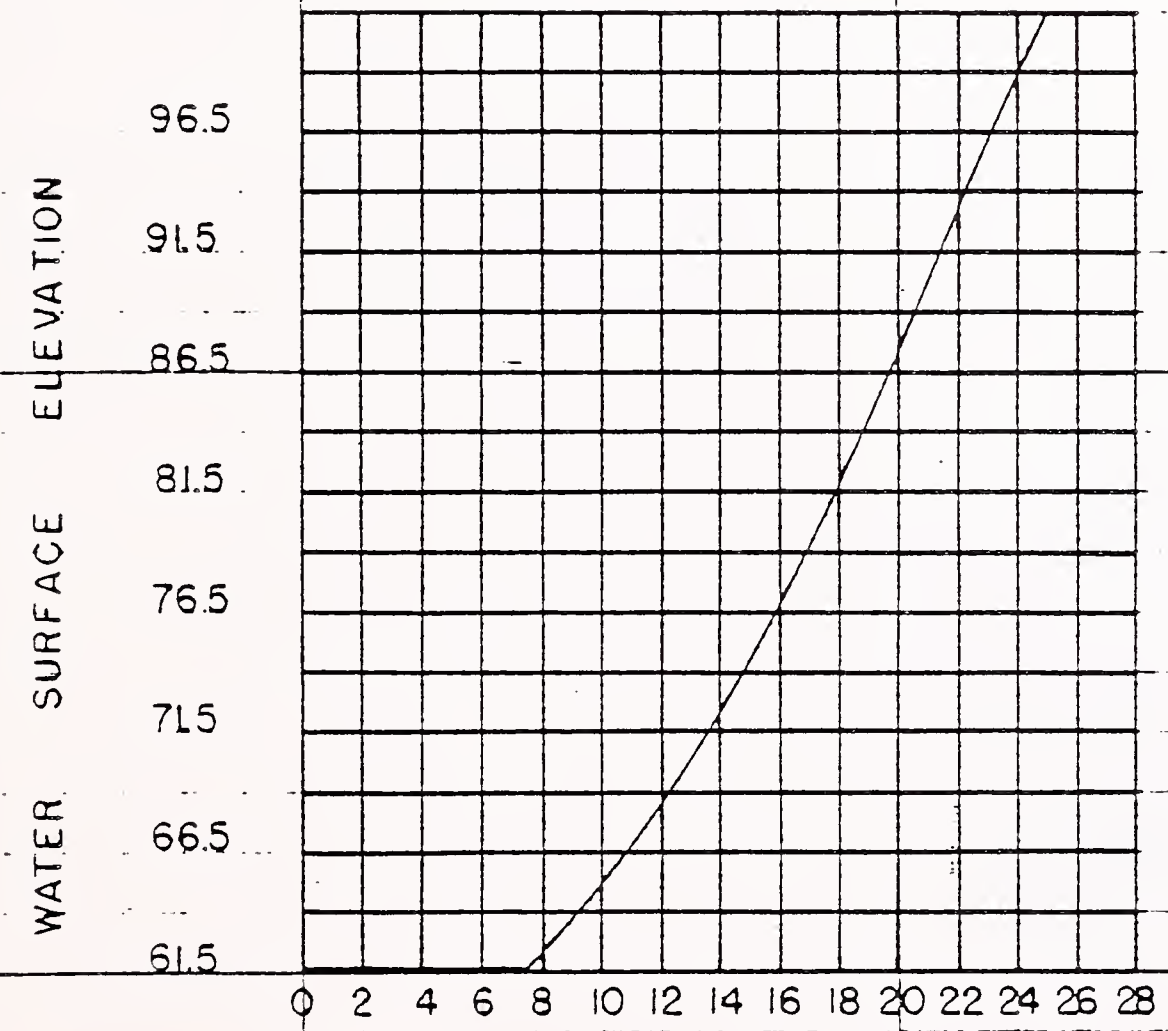
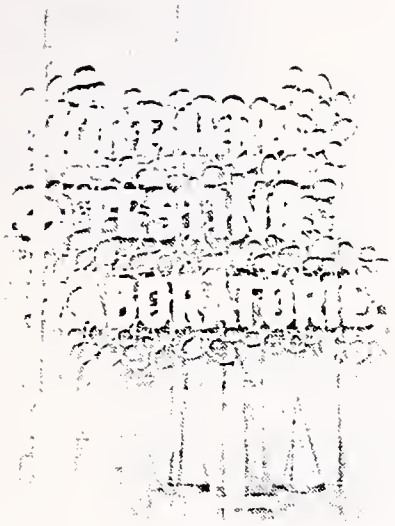


FIGURE 3

APPENDIX 2



REPORT OF LEAKAGE INVESTIGATION
MYSTIC LAKE DAM
BOZEMAN, MONTANA

GREAT FALLS • BILLINGS MONTANA • BOISE • POCATELLO IDAHO • GILLETTE WYOMING

NORTHERN TESTING LABORATORIES

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Construction Quality Control and Inspection
Chemical Analysis and Pollution Control Testing
Great Falls Billings Montana — Boise Idaho — Gillette Wyoming

Phone 453-1641
P. O. Box 951
528 Smelter Avenue
Great Falls, Montana 59403

October 17, 1977

Mystic Lake Water Users Association
c/o City of Bozeman
Bozeman, Montana 59715

ATTENTION: Mr. Arthur Van't Hul, City Engineer

Subject: Leakage Investigation
Mystic Lake Dam

Gentlemen:

At your request and in accordance with our agreement dated August 22, 1977, we have made an investigation of the dam at Mystic Lake to determine possible causes of, and correction for, a "sinkhole" condition and leakage within the dam. We have discussed our findings and recommendations with you as the work progressed, and submitted a preliminary report dated September 29,1977. The report which follows describes our investigations, summarizes our findings, and presents our recommendations.

It appears that leakage is occurring due to embankment soil piping into a break in one of the outlet pipes within the dam. Flow is from the sinkhole along the masonry core wall and into the outlet pipe.

We recommend lining the outlet pipes, grouting the liners and the sinkhole, and a grout curtain along the upstream face of the masonry core wall.

If you have any questions regarding this report, or if we can be of further service, please let us know.

Respectfully submitted,

Dennis A. Williams, P. E.

Walter V. Jones, P. E.

DAW/WVJ/mb
Enclosure
In quadruplicate

REPORT
OF
LEAKAGE INVESTIGATION

MYSTIC LAKE DAM
Bozeman, Montana

TO
MYSTIC LAKE WATER USERS ASSOCIATION
VIA
CITY OF BOZEMAN
Bozeman, Montana

PREPARED
BY
NORTHERN TESTING LABORATORIES, INC.
CONSULTING SOILS ENGINEERS
Great Falls, Montana

OCTOBER, 1977

INTRODUCTION

The purpose of this investigation was to obtain subsurface information relative to a "sinkhole" and leak in the upstream face of Mystic Lake Dam, which was first noticed July 27, 1977, at which time, water was observed entering the face of the dam. Over the next few days, several officials from the Water Users Association and state and federal agencies observed the leak. In order to determine where seepage was emerging, the outlet gates were closed. Muddy water was reported to be exiting through large rocks in the stream channel approximately 300 feet downstream. Theodore T. Williams, P. E. was retained to inspect the conditions, and he prepared a report dated August 8, 1977, in which he summarized the "Chronology of Events" and made other comments relative to his observations and those reported by others.

FIELD INVESTIGATIONS

The geology was carefully mapped, the existing outcrops examined, and available geologic reports on the area studied. Based upon this information, two drill holes and four probe holes were made through the dam into the foundation material. The depth, location, and logs of these holes are shown on the enclosed Drawing No. 77-651-1. Standard penetration resistance tests were made, samples obtained, foundation rock cored, groundwater levels measured, and permeability and pump tests performed, during the drilling program. The sinkhole in the face of the dam was opened, fluorescein dye introduced, and with the gate works closed, water was pumped into the original sinkhole.

Subsequently, as a result of our initial findings, City officials lowered the reservoir and examined the two outlet pipes within the dam with a television monitor. The results of that examination were reported to us by the City Engineer and are included, as applicable, in this report.

LABORATORY INVESTIGATIONS

Samples of foundation soil, embankment material, and bedrock obtained during the field exploration were taken to the laboratory where they were carefully inspected and visually classified in accordance with the Unified Soils Classification System. Moisture content tests were made on all soil samples.

The results of all field and laboratory tests are summarized on the drill logs in the Appendix. This information, along with the field observations, was used to prepare the final test boring logs shown on the Drawing. Sampling and testing procedures are further described in the Appendix.

FINDINGS

Geology

Right Abutment

Bedrock exposed at the right abutment includes units of both the Quadrant Quartzite and Amsden Formations. The bedding strikes generally N. 10° W. to N. 54° W. and dips 36° to 62° northeast. The Quadrant Quartzite underlies a major portion (about three-fourths) of the dam embankment at the abutment, and is partially to completely decomposed to a medium-grained quartzose sand at the contact, becoming somewhat more massive with depth. The decomposed and fractured areas are very permeable, as evidenced by pump tests conducted in the foundation bedrock. Beneath the remainder of the right abutment, bedrock consists of weathered and fractured dolomite, calcareous sandstone, and siltstone units of the Amsden Formation. All are deeply weathered and partially to wholly decomposed.

One unit of dolomitic sandstone, which outcrops about 300 feet downstream, contains numerous solution cavities and channels. This unit could, conceivably, contain adequate open passages to transmit turbid water from a leak in the dam. However, for this to be the case, the water would have to flow through three permeable, but noncavernous, units -- one of quartzite, one of dolomite, and one of siltstone -- for a distance of about 200 feet before it could enter the cavernous unit. This would almost certainly filter all of the turbidity and algae from the leaking water before it reached an open passage.

Left Abutment

The entire left abutment and 50 to 60 percent of the left side of the dam foundation is a recent (±100 years) landslide. Downstream there is evidence of present landslide activity. The landslide consists of large blocks, intermixed with boulder, cobble, gravel, sand and silt-sized material composed of andesite breccia with some basaltic inclusions. The slide apparently encroached the stream channel, probably forming a dam which created Mystic Lake. The present stream is eroding downward along the contact between the bedrock on the right and the slide rubble on the left. The stream channel for 500 to 600 feet downstream is at the contact between the two materials.

Dam Embankment

The dam is an earth fill structure. Construction drawings prepared in 1903/04 indicate a masonry core wall approximately 2 feet thick was constructed from a point beneath the upstream edge of the crest, extending through the earth fill, and 10 feet below the outlet pipes to the bedrock foundation. The embankment penetrated with our drilling equipment and exposed by excavating into the throat of the sinkhole is silty, sandy, or gravelly clay with lenses of silty sand.

While drilling, there were "tight" zones and some zones of considerable water loss, indicating permeable lenses or internal erosion channels, especially near the core wall. We believe that one hole encountered the masonry core wall (see Probe Hole 104).

Sinkhole

The location of the original sinkhole was well documented when we were performing the field investigations, but excavation with a backhoe had masked the exact opening. The location of the exiting muddy water was reported about 300 feet downstream from the dam. The observers described the leak outlet as being in the stream channel at a waterfall composed of large andesite breccia blocks and boulders from the slide.

We considered the possibility of the sinkhole leak coming out of the downstream location, but it did not seem likely. The reworked slide mass was expected to be very permeable and it was unlikely that it would contain an isolated tube extending 300 feet downstream to transmit the muddy water to the reported exit. The escaping water would more likely emerge near the toe.

To determine accurately where the sinkhole water was emerging, we planned to inject a fluorescein dye into the sinkhole and see where it emerged. However, the sinkhole would not take water as we desired. Therefore, a hydraulic probe was used to jet the hole open. After several hours of jetting, the hole began to take water at about 20 to 30 gallons per minute.

At this time (1:10 P.M., September 22, 1977), the outlet gates were closed and we carefully observed the area from the dam approximately 300 to 400 feet downstream. Muddy water was noted exiting between boulders at the downstream location, reported by other observers, as well as at other locations even further downstream. At first it appeared this was the location of the emerging leak, but after several minutes, the water ceased running and the stream bed "dried" up at this location.

During this time, at 2:00 P.M., one cup of concentrated fluorescein dye was introduced into the sinkhole and water was pumped into the hole at an increasing rate, to about 80 gallons per minute by 2:10 P.M. Dye was observed seeping out of the upstream face of the dam into the lake near the pump intake at lake level and about 10 feet below the lake level. This was directly upstream of the sinkhole.

At 2:35 P.M. the quantity of flow was increasing at the outlet basin, and within ten minutes it became murky and a slight indication of green dye appeared. By 2:55 P.M. the dye coloration became strong and a flow of approximately 80 gallons per minute was issuing forth at the outlet basin. Observation and recording were continued until 3:30 P.M. when the outlet gates were opened. Immediately upon opening the outlet gates a gush of muddy water, green with dye, flowed for several minutes, indicating the outlet pipes must have been partially full of the water injected in the sinkhole.

Spillway

We noted gravel below some of the weep holes in the spillway and were able to probe 4 to 5 feet into one of the holes. To determine whether or not the spillway bedding was partially eroded, we drilled ten holes through the concrete at suscept locations, to examine the bedding. We found the bedding intact. It now seems probable that the gravel dispersal was caused by burrowing rodents entering the weep holes and removing the gravel. A dead rodent was retrieved from one weep hole.

TELEVISION MONITORING

Subsequent to our initial report of findings, the lake was lowered to the depth of the valve chamber and, on October 4 and 5, 1977, City crews inspected both of the outlet pipes with a television monitor. The findings were reported to us by the City Engineer as follows:

> The 12-inch pipe is broken abruptly at the upstream face of the core wall and displaced about 3 inches. The remainder of the 12-inch pipe appears sound and clean, with some long bends and locally out-of-round areas.
>
> The 16-inch pipe is intact throughout the area examined, but shows some bending and out-of-round areas.

ANALYSIS

Dam Embankment

The dam embankment appears to be constructed, in general, of clay-silt-sand-gravel mixtures, which, when properly compacted, provide a good water barrier. However, near the right abutment where the sinkhole occurred and where we drilled, there are permeable zones. Evidences of this are:

> The sinkhole.
>
> Large water loss -- both during drilling and during permeability tests.
>
> Seepage traveling quickly from the sinkhole to the upstream face.

Similar conditions could exist at other locations in the dam.

It appears that there is a general weakness at the location of the sinkhole. This may be due to a wooden spillway that was installed, then removed and backfilled at this location. Also, it may be due, in part, because of abutment construction at the bedrock-fill contact.

Other seepage and "loose" areas in the fill appear to be confined to the contact area between the fill and the masonry core wall and at or near the break in the outlet pipes.

Foundation

The weathered, decomposed, and fractured bedrock at the base of the embankment is extremely permeable. Fairly large volumes of seepage water are probably flowing through this material and exiting downstream of the dam. No erosion or gross instability is apparent as a result of the seepage. Exit water appears clean and, since most of the seepage water exits into the drainage below and is ultimately available for use, the foundation seepage does not appear to be a critical problem.

Sinkhole

The sinkhole leak has relatively direct access to the displacement hole in the 12-inch outlet pipe. It required only 45 minutes for the dye injection to flow from the sinkhole into the pipe and emerge at the outlet basin. The path appears to be fairly horizontal at elevation 88.8 toward the masonry core which it intersects near the concrete spillway, thence along the wall to the 12-inch outlet pipe rupture at about elevation 46. The hole, at the time of the investigation, accepted 80 gallons per minute, and some sand-sized particles flowed into the break in the 12-inch pipe.

Concrete Spillway

The new concrete spillway is well bedded and in sound condition. The weep holes should be screened.

Originally Reported Exit Area

The turbid water observed in the waterfall approximately 300 feet below the dam, and reported to be the location where the sinkhole water was exiting, is the result of changing the flow regime of the creek by shutting the gates off. This is explained by noting that as the flow decreases, water seeps through the stream bed 50 to 100 feet upstream of the reported exit, travels underground through a network of channels through the pervious landslide debris, and emerges between the boulders. As it does this, silt from the creek floor (landslide) is carried outward into the channel and appears as muddy water. This apparently does not happen under full flow conditions, as hydraulic gradients differ from the reduced flow or nonflow condition.

Repair

After discussion regarding the nature of the break in the 12-inch pipe and the apparently good condition of the interior face of both of the outlet pipes, we considered using a pressure "boot" at the area of the break and placing a grout repair at the break zone. If this type of repair could be accomplished, it would be considerably less costly than reshaping the break area to accept a liner. We conclude that the grout patch would not be an acceptable solution for the following reasons:

Cavitation will be severe at the abrupt direction change in the pipe. This could either erode the grout or erode the pipe at some location away from the grout patch.

The outlet pipes have been in place since 1904 and, even though the interior appears in fairly good condition, the pipes have probably been eroded due to cavitation of the interiors and corroded due to oxidation of the exterior.

There is a possibility that even though the 16-inch pipe is only bent at this time, it will rupture at the masonry wall in the future. There is obviously a zone of severe difference in rigidity between the compressible fill and the rather incompressible masonry core.

We further conclude that the 12-inch pipe should be reshaped to accept a liner at the break zone. This may be accomplished with a reamer or with a drilled and braced shaft from the top.

The entire liner should be grouted, as well as the portion of the sinkhole, from the pipe break to the bottom of the vertical hole in the dam face. Grouting of the sinkhole may require a "curtain" to be constructed toward the reservoir side of the sinkhole, since it appears that this area of embankment is weak and grout may exit toward the face. The last 15 feet of the sinkhole to the dam face should be filled with compacted clay rather than grout. This will avoid a rigid mass within the compressible embankment soil, which could cause future weakness.

Since there is a general zone of weakness and open voids, apparently at the interface between the core wall and the fill, a grout curtain should be constructed at this interface. The curtain should extend vertically to the base of the wall and laterally to well beyond the "slurry trench" (see Drawing No. 77-651-1). The curtain should be constructed on the upstream face of the masonry wall.

RECOMMENDATIONS

1. Both outlet pipes should be lined and grouted. It will probably be necessary to utilize a reaming device to rebore the opening in the 12-inch pipe at the ruptured area.

2. Repair of the existing sinkhole and prevention of future, similar problems should include the following:

   a. After the outlet pipe repair is completed, the sinkhole should be pumped full of grout, except for the 15 feet nearest the dam face, which should be filled with a highly plastic clay or a soil-bentonite mixture compacted in layers.

b. The top of the masonry core wall should be accurately located by two or more backhoe pits and other probing.

c. A grout curtain should be constructed abutting the upstream side of the core wall, extending from the high water level completely through the fill to the foundation and from the right abutment at least 50 feet past the outlet works toward the left abutment.

3. All repair work should be inspected by a qualified soils engineer.

The recommendations given in this report are based on the results of the field and laboratory investigations, combined with interpolation of the subsurface conditions between boring and probe locations. The nature and extent of variations between the borings and probes may not become evident until construction. If variations are then exposed, it will be necessary to reevaluate the recommendations of this report.

APPENDIX

EXPLORATION AND LABORATORY TESTING

Exploration

Field exploration is performed using truck or skid mounted rotary drilling machine equipped with either augers, tricone rock bits, or coring apparatus. Standard penetration testing and undisturbed sampling can be performed through our hollow stem auger which serves as casing. When drilling in large, dense gravel, rock fragments or bedrock, special casing is usually required to maintain an open hole. The soils are continuously logged by our field personnel and classified by visual examination in accordance with the Unified Soils Classification System.

Samples of soils are taken at frequent intervals in the boring excavation. Disturbed samples are normally taken by the standard penetration test. This test is made by driving a 2-inch O.D. split spoon sampler 18 inches into the soil by striking it with a 140 pound hammer dropping 30 inches. The total number of blows required to advance the sampler the second and third six inch increments is the standard penetration resistance. Occasionally, a cone penetrometer will be driven continuously from the ground surface to locate soft zones or to simulate the driving of piling into subsurface soils. The cone is 1-13/16 inches in diameter and is driven with the same hammer and dropping distance as the standard penetrometer. Undisturbed samples are obtained from layers of soil that are critical to the analysis. Samples of representative soils are obtained by pushing, or possibly driving, a thin-walled steel sampler into the soil layer. The soil is retained in brass rings of 2.00 and 2.50 inches in diameter, and 1.00 inches in height. Normally, the central six inch portion of the sample is retained in close-fitting, plastic, waterproof containers which are in turn placed in cushioned boxes for shipment to the laboratory. Occasionally, thin-walled shelby tubes are used to sample sensitive soils that are easily disturbed.

Under certain conditions and with certain project requirements, in-place vane shear, percolation, resistivity and/or California bearing ratio tests may be performed in accordance with standard procedures.

Laboratory Classification and Testing

The field classification is verified in the laboratory, where all of the samples are classified by someone other than the person who made the field classification. The classification process in the laboratory normally includes estimation of the percents of gravel or rock fragments, sand, silt, and clay fractions, and the liquid and plastic limits. The natural moisture content of all of the fine-grained soil and bedrock samples is determined.

Based on the classification tests, one or more of each representative type of soil encountered is selected for more detailed analysis. The data from the field and the laboratory investigations is used to prepare the final test boring logs (shown on the Drawing).

LOGS OF EXPLORATIONS

EXPLANATION OF ABBREVIATIONS

SSS (SPT)	Standard penetration resistance test -- results recorded as the number of blows of a 140-pound hammer falling 30 inches required to drive a 2-inch O.D. split sample spoon the second and third 6-inch increments of an 18-inch distance.
LSS	Modified penetration test -- results recorded as the number of blows of a 140-pound hammer falling 30 inches required to drive a 2.5-inch O.D. split sample spoon the second and third 6-inch increments of an 18-inch distance.
CPT	Cone penetration test -- results recorded as the number of blows of a 140-pound hammer falling 30 inches required to drive a 1-13/16-inch-diameter cone one foot.
SRS	Split barrel ring sample 2-inches I.D. for taking undisturbed samples.
LRS	Split barrel ring sampler 2.5-inches I.D. for taking undisturbed samples.
STS	Shelby tube sample for taking undisturbed samples (2" to 3-5/16" I.D.).
Sack	Sample of disturbed soil placed in canvas bag.
GWL	Groundwater level on day of completion of field investigations.
FD	In-place field density test.

CONSULTING GEOTECHNICAL ENGINEERS

Great Falls Billings Montana — Boise Pocatello Idaho — Gillette Wyoming

LOG OF EXPLORATION HOLE

PROJECT: MYSTIC LAKE DAM

JOB NO.: 77-651

DRILL TYPE: SOIL

ROCK K & S skid - Nx Rockbit, Nx Core

DRILLED BY: E. Adams

LOGGED BY: D. F. Goodell

REMARKS: 25.8' of perforated plastic pipe installed in Drill Hole.

HOLE NO. DH 1

SHEET 1 OF 2

LOCATION 35' east of right abutment; 2 west of west edge of spillway.

ELEVATION: TOP OF HOLE 102.1

GROUNDWATER 77.5

DATE: HOLE STARTED 9/15/77

HOLE COMPLETED 9/16/77

DEPTH (Feet)	LEGEND	CLASSIFICATION AND DESCRIPTION	SAMPLE SYMBOL	S.P.T. (N) (BLOWS/FT.)	MOISTURE CONTENT (%)	IN-PLACE DRY DENSITY (pcf)	L.L. %	P.I. %	GRAVEL %	SAND %	SILT %	CLAY %
0.0		TOPSOIL; Organic matter.										
0.3		FILL, Clay, Gravelly; Considerable silt, moist, firm.	LSS	17	14							
5.0		FILL, Gravel, sandy, considerable silt and clay, moist, compact.	LSS	23	13							
8.5		FILL, Clay, Silty; scattered gravel, some sand, moist, firm.	SPT	8	25							
12.5		GRAVEL, Sandy; (decomposed quartzite) moist compact to medium dense. Water loss at 12.5' - 16.8'.	LSS	24	12							
18.3		QUARTZITE, fractured weathered wet to saturated, dense to very dense.										

Percolation test at 10.0' - 16.8' 0.01' per minute per inch of drop.

NTL 150

CONSULTING GEOTECHNICAL ENGINEERS

Great Falls Billings Montana — Boise Pocatello Idaho — Gillette Wyoming

LOG OF EXPLORATION HOLE

PROJECT: MYSTIC LAKE DAM

JOB NO.: 77-651

DRILL TYPE: SOIL

ROCK K & S skid - Nx Rockbit, Nx Core

DRILLED BY: E. Adams

LOGGED BY: D. F. Goodell

REMARKS: 25.8' of perforated plastic pipe installed in Drill Hole.

HOLE NO. DH 1

SHEET 2 OF 2

LOCATION 35' east of right abutment; 2' west of west edge of spillway.

ELEVATION: TOP OF HOLE 102.1

GROUNDWATER 77.5

DATE: HOLE STARTED 9/15/77

HOLE COMPLETED 9/16/77

DEPTH (Feet)	LEGEND	CLASSIFICATION AND DESCRIPTION	SAMPLE SYMBOL	S.P.T. (N) (BLOWS/FT.)	MOISTURE CONTENT (%)	IN-PLACE DENSITY (pcf)	L.L. %	P.I. %	GRAVEL %	SAND %	SILT %	CLAY %
20		Water loss at 21.0' - 21.5'.										
		QUARTZITE, fractured										
		weathered	LSS	84	9							
		wet										
		to										
		saturated,										
		dense										
		to										
		very dense.										
24.6		GWL										
25.0		Water loss at 25.0' - 28.0'.	LSS	50/0.0								
		QUARTZITE,										
		fractured,										
		saturated	Nx core	77%	RQD = 0							
		hard.										
28.0		BOTTOM OF HOLE										

NTL 150

CONSULTING GEOTECHNICAL ENGINEERS

Great Falls Billings Montana — Boise Pocatello Idaho — Gillette Wyoming

LOG OF EXPLORATION HOLE

PROJECT: MYSTIC LAKE DAM

JOB NO.: 77-651

DRILL TYPE: SOIL

ROCK K & S skid, Nx Rockbit, Nx Core

DRILLED BY: G. Skaer

LOGGED BY: W. Henning

REMARKS:

HOLE NO. DH 2

SHEET 1 OF 3

LOCATION Centerline of dam, 79' E. of right abutment; 3' E. of E. edge of

ELEVATION: TOP OF HOLE 102.0 spill

GROUNDWATER 58.1 (9/19)

DATE: HOLE STARTED 9/17/77

HOLE COMPLETED 9/17/77

DEPTH (Feet)	LEGEND	CLASSIFICATION AND DESCRIPTION	SAMPLE SYMBOL	S.P.T. (N) (BLOWS/FT.)	MOISTURE CONTENT (%)	IN-PLACE DRY DENSITY (pcf)	L.L. %	P.I. %	GRAVEL %	SAND %	SILT %	CLAY %
0.0		TOPSOIL, organic matter.										
0.3		FILL, Clay, Gravelly; considerable sand, moist, stiff.	LSS	18	18							
5.0		FILL, Clay, Sandy; considerable gravel and silt, some gravelly clay and silty zones, damp, soft to medium firm.	LSS	7	24							
10			LSS	9	23							
15		80% water loss at 15.1' - 19.8'.	LSS	18	24							
20												

Percolation test at 11.0' - 12.0', 40 minutes per inch of drop.

Pump test at 15.1 - 21.3, 0.12 cubic feet per minute.

NTL 150

ied

CONSULTING GEOTECHNICAL ENGINEERS

Great Falls Billings Montana — Boise Pocatello Idaho — Gillette Wyoming

LOG OF EXPLORATION HOLE

PROJECT: MYSTIC LAKE DAM

JOB NO.: 77-651

DRILL TYPE: SOIL

ROCK K & S skid, Nx Rockbit, Nx Core

DRILLED BY: G. Skaer

LOGGED BY: W. Henning

REMARKS:

HOLE NO. DH 2

SHEET 2 OF 3

LOCATION Centerline of dam, 79' E. of right abutment; 3' E. of E. edge of

ELEVATION: TOP OF HOLE 102.0 spillw.

GROUNDWATER 58.1 (9/19)

DATE: HOLE STARTED 9/17/77

HOLE COMPLETED 9/17/77

DEPTH (Feet)	LEGEND	CLASSIFICATION AND DESCRIPTION	SAMPLE SYMBOL	S.P.T. (N) (BLOWS/FT.)	MOISTURE CONTENT (%)	IN-PLACE DENSITY DRY (pcf)	L.L. %	P.I. %	GRAVEL %	SAND %	SILT %	CLAY %
20		FILL, Clay, Sandy; considerable gravel and silt, some gravelly clay and silty zones, damp, soft to medium firm.	LSS	12	24							
			LSS	8	25							
		65% water loss at 29.0'.										
30			LSS	11	16							
37.5		FILL, Clay, Silty; considerable gravel and sand, gravelly lenses.										

Pump test at 35.1' - 40.0', 0.30 cubic feet per minute.

ed

NTL 130

CONSULTING GEOTECHNICAL ENGINEERS

Great Falls Billings Montana — Boise Pocatello Idaho — Gillette Wyoming

LOG OF EXPLORATION HOLE

PROJECT: MYSTIC LAKE DAM

JOB NO.: 77-651

DRILL TYPE: SOIL

ROCK K & S skid, Nx Rockbit, Nx Core

DRILLED BY: G. Skaer

LOGGED BY: W. Henning

REMARKS: 55' of perforated plastic pipe installed in Drill Hole.

HOLE NO. DH 2

SHEET 3 OF 3

LOCATION: Centerline of dam, 79' E. of right abutment; 3' E. of E. edge of

ELEVATION: TOP OF HOLE 102.0 spillwa

GROUNDWATER 58.1 (9/19

DATE: HOLE STARTED 9/17/77

HOLE COMPLETED 9/17/77

DEPTH (Feet)	LEGEND	CLASSIFICATION AND DESCRIPTION	SAMPLE SYMBOL	S.P.T. (N) (BLOWS/FT.)	MOISTURE CONTENT (%)	IN-PLACE DENSITY DRY (pcf)	L.L. %	P.I. %	GRAVEL %	SAND %	SILT %	CLAY %
40.0		FILL, Clay, Silty; considerable gravel and sand, some gravel zones, saturated; stiff.	LSS	28								
43.9		GWL										
44.0		QUARTZITE; weathered and decomposed to 46.0', then fractured, saturated dense to very dense.	LSS	50/0.2								
		Water loss at 48.0' - 51.6'.	Nx core	50% RQD = 0								
			Nx core	50% RQD = 0								
54.3		BOTTOM OF HOLE.										

Pump test at 45.1' - 54.3' = 5.0 cubic feet per minute at static groundwater level of 36.0'.

NTL 150

APPENDIX 3

THEODORE T. WILLIAMS, P.E.
REGISTERED PROFESSIONAL ENGINEER · MONTANA #861-E
319 SOUTH THIRD AVENUE — BOZEMAN, MONTANA 59715

TELEPHONE (406) 587-7669

August 8, 1977

To the Officers and Stockholders
Bozeman Creek Reservoir Company
Bozeman, Montana 59715

Gentlemen:

On Thursday, August 4, 1977, Mr. Donald Strang and I made an inspection of the Mystic Lake Dam. My visit was at the telephoned request of Mr. Kenneth Kraft.

At the time of our visit on Thursday, there was no evidence of leakage through the dam, other than the normal seepage to be expected through any earth dam. Mr. Strang pointed out, however, the spot on the upstream face of the dam where water had been observed to be entering the dam several days previously, as well as the spot in the outlet channel downstream from the dam where muddy water had been seen issuing from the rocks. Both spots were well marked.

Mr. Strang and I made a number of reference and elevation measurements, and collected some soil and water samples for laboratory analysis. Mr. Strang also described to me the chronology of events of the preceding week, and his description is incorporated into the statements below.

CONCLUSIONS AND RECOMMENDATIONS

1. Water level in the reservoir is low enough so that there is no danger at present to the dam.

2. Repairs must be effected before the reservoir is filled. It is evident that water flowed through the crack or channel at a high rate of speed, and hence was piping (removing additional earth material from the dam). This condition, if allowed to continue, would result in enlargement of the crack or channel, and could ultimately result in failure of the dam. Repairs must therefore be completed before next spring. The reservoir has two outlet gates, 16 inches and 12 inches in diameter. When the reservoir is full these gates have capacities of about 40 and 20 cfs respectively; for a total capacity of 60 cfs. The hydrologic studies I made in 1959 for design of the present spillway showed a 100-year return flow of 350 cfs; so even if the outlet gates were to be left wide open the reservoir might fill next spring.

3. The leak is close (within 20 feet) of the west abutment of the dam. Water appeared to be going vertically downward at its entry point, and of course its path through the dam is not known at this time. But I think it is likely that the flow path is around the end of the core wall. The leak may result from an imperfect tie of the dam into the abutment.

Masonry core walls for earth dams are not considered good engineering practice in modern design. They are not structurally strong enough to resist the water pressure, hence it must always be assumed that they are cracked. A second drawback is the difficulty of achieving proper compaction of the earth fill adjacent to the core wall.

Mystic Lake dam, of course, was built with a masonry core wall which extended to the original high water line. The dam has been extended at least twice, and I don't know the elevation of the top of the wall. The spillway which was built in 1960 was to have been tied to the top of the core wall and I presume that was done.

The Mystic Lake Dam has performed well for 60 years. It has withstood several severe earthquakes with no previous sign of distress. Except for the present leak the dam appears to be sound.

4. Several strategies for repair have been suggested. One proposal is to introduce bentonite into the crack at the upstream face of the dam. This seems infeasible because the lake would have to be full enough for water to flow into the crack. This could be dangerous. Also, if the crack or channel is large, the bentonite would be swept through the dam along with high velocity water and would not be trapped.

Another suggestion is to place a large amount of earth material on the upstream face of the dam, effectively building the dam farther out into the lake and hence covering over whatever leaks exist. This is an expensive proposal because an enormous amount of material would be required, extending from the base of the dam to the top. The outlet works might have to be extended. Careful size gradation would be necessary to prevent the new material from being drawn into the crack. (No amount of dam "extension" will make it seepage-proof. All earth dams seep some water, and are fully saturated below the "flow line" of the dam.) A large amount of rip-rap would also be required. I fear this suggestion would end up being nearly as expensive as a new dam.

A third possibility suggested is a bentonite or concrete blanket over the face of the dam. A bentonite blanket could possibly stop the leak, and would be beneficial in reducing seepage in general. A concrete blanket, besides being extremely expensive, would surely crack and would probably not succeed in stopping the leak. I'm afraid the crack may be too extensive to be stopped by a bentonite blanket, and I therefore don't recommend it - at least not as the initial strategy.

5. The alternative I suggest, at least initially, is to excavate from the front face of the dam in the vicinity of the leak, hopefully locate channels that can be traced, and backfill with select material and careful compaction. I suggest the following procedure:

a. Excavate in the vicinity of the leak. This should be done carefully and under close supervision to try to detect the channel or channels followed by the water.

b. If channels are detected excavation must be followed along them, if possible, as far as the core wall. I don't think excavation downstream of the core wall would be necessary. Method of backfilling would be decided upon after excavation, and might include placement of some concrete at the point where the excavation is terminated.

c. If a channel cannot be detected, extensive excavation must be performed. The extent of excavation would have to be decided upon after the work has begun, and would depend upon the conditions found. A hole 15 feet in radius centered on the point of entry of the water might be sufficient. When it is concluded sufficient excavation has been accomplished, the method of backfilling would then be determined.

CHRONOLOGY OF EVENTS

Wednesday, July 27, 1977. Water was observed to be entering the dam, accompanied by a loud roar from within the dam. Point of entrance about 35 feet west of centerline of spillway, and at about elevation 90.2 to 90.7. (Spillway crest elevation = 96.20 according to "Plans for Improvements at Mystic Lake, 1959"). Water level in the lake was somewhat above the point of entrance. Evidence of algae entering dam with water. Outlet gate was temporarily closed, and water was observed to shoot out of a pool on the cataracts in the outlet channel 200 to 300 feet downstream from end of spillway (using spillway crest as Sta 0+00, the jet was at Sta 3+85 to 4+85). This point is at least 15 feet vertically below end of spillway (spillway floor ends at elevation 55.75). Water was very murky, and came from a jet 3 to 4 inches in diameter. It was not under special pressure, but just appeared to be flowing from within the rocks. One estimate of flow rate was 10 miners inches (0.25 cfs).

(I speculated that the jet might have been a 3-inch diameter circular jet discharging horizontally, and striking a point 2 feet horizontally out from and 1 foot vertically below the point of efflux. If this were the case, the flow rate would have been 16 miners inches (0.39 cfs).)

Thursday, July 28, 1977. U.S. Forest Service representatives visited the dam. Water level in the lake at about point of entrance into the dam, elevation 90.2 to 90.7. Sound from within the dam very noticeable, but diminished from Wednesday. A six-foot long bar was jabbed vertically into the dam at point of entrance, and could be inserted its full length except when it hit large rocks. The outlet gate was temporarily closed, and muddy water was again observed issuing from the same point in the outlet channel. But the murky pool did not persist as far downstream as it had on Wednesday.

Friday, July 29, 1977. Sound from within dam had nearly stopped. Water level in the lake about 6 inches below point of entrance - about elevation 89.7 to 90.2. Forest Service inspectors yesterday had excavated a hole 1 foot square and 1 foot deep at the point of entry on the face of the dam. Today some evidence of leakage into the dam by water percolating through the rocks and being visible in the bottom of the one-foot hole. Again the outlet gate was closed temporarily - drainage persisted from the rock outcrop of the outlet channel, but not especially muddy from the suspected leakage outlet.

Green dye was introduced into the water at the point of entrance into the dam. Some of the green dye (and algae) flowed into the dam, but no evidence of dye could be detected downstream.

Sometime Thursday night or early Friday morning the water level in Bozeman Creek at the mouth of the canyon was noted to have dropped 125 miners inches (3.12 cfs). The drop could possibly have been from a reduction in leakage through the dam.

Saturday, July 30, 1977. No evidence of seepage entering the dam, no sound from within the dam.

Thursday, August 4, 1977. (Strang and Williams visit). Water level in lake about elevation 87.37. We closed outlet gate temporarily to observe seepage. Nearly all flow was stopped - much mor complete closure than any day in previous week. At the point where the muddy water had shot out last week there was a very small flow coming from the rocks, with tiny bits of algae coming out as well. Except for the algae particles, the water was perfectly clear.

SOIL SAMPLES

Three soil samples were collected for grain size analysis.

Sample 1. - from upstream face of dam at point where water had entered dam.

Sample 2 - from pool below dam where muddy water had issued.

Sample 3 - from a typical pool 15 or 20 feet upstream from point where muddy water had issued.

TABLE 1

Cumulative Percentage of Particles Finer than Sieve Size Indicated.

Sieve Size	Sample 1	Sample 2	Sample 3
1.00 inch	70.1 %	53.2 %	48.8 %
0.75 inch	61.7	46.6	38.0
0.375 inch	41.3	26.7	20.8
0.25 inch	26.8	15.1	10.8
0.125 inch	18.4	9.5	6.9
0.025 inch	8.0	2.2	1.8
0.0167 inch	6.3	1.1	0.8
0.01 inch	3.4	0.6	0.4
0.005 inch	1.6	0.3	0.2

ADDITIONAL COMMENTS

1. The point of entry into the dam is evidently directly below the center-line of the original spillway which was replaced in 1960. The old spillway was a concrete structure which terminated in a timber flume. The present leak begins 5-1/2 or 6 feet vertically below the crest elevation of the old spillway. I did not observe the removal of the old structure, so do not know the extent of its foundation, nor do I know for certain that the old structure was entirely removed. But I would not have expected the foundation of the old structure to extend vertically down to the elevation of the present crack, and I can't think of any reason why there should be a connection between the old spillway and the present leak.

The soil analyses do not shed any particular light on the present problem.

Samples 2 and 3, the two samples taken from the outlet channel below the dam, are almost identical. Neither sample has appreciable fine material. Since both samples were from the bed of the outlet channel, and have been subjected to high velocity water I would not have expected any fine particles. But I had thought possibly considerable fine material would be found at the point where mud and water had presumably been coming through the dam. This was not the case. In all three samples some selectivity of sampling was exercised because larger rocks (3 inches and larger) were present and could have been included in the sample.

3. One water sample was collected, from the pool on the cataracts below the dam where water is presumed to have come through the dam. At the time of our visit this water appeared to be perfectly clear, except for some tiny particles of algae. Algae, however, is present in all water issuing from the dam through the outlet gates, so it might have been more significant had algae not been present in the pool we examined.

Respectfully submitted,

Theodore T. Williams

Theodore T. Williams, P.E.

APPENDIX 4

DEPARTMENT OF NATURAL RESOURCES & CONSERVATION
WATER RESOURCES DIVISION

32 SOUTH EWING
HELENA, MT 59601

THOMAS L. JUDGE, GOVERNOR
TED J. DONEY DIRECTOR

December 5, 1979

Department of the Army
Seattle District, Corps of Engineers
P.O. Box C-3755
Seattle, Washington 98124
Attn: Ralph Morrison

Re: CH_2M Hill final Dam Safety Inspection report on Mystic Lake Dam (MT 880)

Dear Ralph:

We have reviewed the above referenced report and with the exception of a few comments which are itemized below have found the report to be very good.

1) Under Pertinent Data on page V - This dam is located in Gallatin County and not Madison County as stated.

2) On page 17, second paragraph - Statement should be made that estimated 48 hour PMP is 110% of 24 hour PMP.

3) On page 18, in paragraph 2.2.4 (Flood Routing) - Evaluation of the dam should be based on percentage of PMF peak flow rather than on a percentage of PMF volume as has been done in the report.

4) On page 26, in paragraph 2.4.3 (Warning System) - Civil Defense should have top priority over all of the other parties to be notified in the event of rapid developing or catastrophic failure situations in the emergency warning procedure. The Civil Defense has developed an organized plan for emergency situations.

Thank you for this opportunity to review and comment on the final draft report on Mystic Lake Dam.

Sincerely,

Richard L. Bondy

Richard L. Bondy, P.E.
Chief, Engineering Bureau

RLB:LT:mb

THE CITY OF BOZEMAN
411 E. MAIN ST. P. O. BOX 640 PHONE (406) 586-3321
BOZEMAN, MONTANA 59715

December 13, 1979

Mr. Sidney Knutson, P.E.
Dept. of the Army
Seattle District, Corp of Engineers
P.O. Box C-3755
Seattle, WA 98124

RE: Mystic Lake Dam, Bozeman, Montana

Gentlemen:

We have reviewed the final draft, Phase I Inspection Report National Dam Safety Program, Mystic Lake Dam, Bozeman, Montana, and have the following comments:

1. P. 6 We seriously question that a failure of Mystic Lake Dam would cause extensive property damage and possible loss of life. The dam is located 12 miles up a canyon, and there are several wide spots that would cause a dampening of the peak. The area immediately downstream of the mouth of the canyon opens up onto flat allivial fans that would spread any waters over a fairly wide area.

2. The City of Bozeman in coordination with HUD has been working with the Soil Conservation District under a 566 grant to determine flood hazard areas and protection measures including another reservoir halfway between Mystic Lake and the mouth of Bozeman Canyon. The SCS developed a PMF flood for Mystic Lake and routed it down to the proposed dam. I am including a letter from the SCS regarding their hydrologic studies. Being a hydrologist myself, I think that the rational and results of their study are much more realistic than the PMF described in the Corps report. The storms of record that may have led to PMF floods were the result of moist air masses from two to three (2-3) directions colliding over a point. This requires certain Geographic features to make this possible which are not present here. Also the supposition that one is going to get these midsummer storms to fall on snow pack on frozen ground is utterly ridiculous. The small Mystic Lake water shed acts like a sponge. Much of the area is a mixture of forest organics mixed with landslide debris, rocks and mud that has sloughed off the adjacent ridges. This area gets a snow pack before it freezes and seldom is the ground really frozen.

3. P. 11 The crack in the lower spillway wall occurred shortly after the installation in 1968-69. Some settling was noted and affected portions were mudjacked. Our inspection by Northern Testing in 1977 included boring of the spillway and it was found to be sound.

4. P. 13 I question the 80 gpm seepage figure. This has been constant for the years that I have inspected the dam, is always clear and is probably toe drainage along the pipe bedding. It has never appeared to be a problem and was inspected by Walt Jones, Northern Testing Labs as well as their geologist who spent almost two weeks on site.

5. P. 13 I don't know where the idea of the outlet pipes being out of round originated. They are as round as they were 75 years ago and appear to be in reasonably good shape. Cast iron has a lot longer life than 75 years and this pipe outside of a few tuburculs looks like it is in very good shape. I have viewed it on two occasions, 1977 and 1978, by television along with other water department people and did not notice any problems.

6. P. 17 I disagree that the critical meteorlogic and hydrologic conditions are possible on this water shed. We are in the shadow of the high mountains of Yellowstone Park and are protected by mountain ranges in almost all directions as well. The frozen ground theory and zero infiltration are academic and do not fit observed conditions. The base flow of 80 c.f.s. is high. Eleven years of record 1937-1947 show an average of 53.49 c.f.s. for May-June at a point about two miles above the mouth of the canyon which includes almost the total flow from Bozeman Creek. Information by Mr. Thorpe in August 25, 1891 and November 26, 1897 showed 2.46 and 2.0 c.f.s. respectively at Mystic Lake. This corresponds to our observations in past years. It was observed by Mr. Ted Williams in studying run-off records of Bozeman Creek and the adjacent Hyalite Creek that the Bozeman drainage produced only about one-half the water as does the Hyalite drainage. This is probably due to the high retention characteristics of the water shed. For this reason, I can accept that 6.78 inches run-off from a 6 hour PMF of 11.8 inches much quicker than I can accept 19.81 inches from a 18.1 inch - 72 hour storm of the Corps.

7. P. 18 The supposition that the core wall is founded on river alluminum is ridiculous.

8. P. 20 The conduit settlement may be connected with the 1959 earthquake, but I doubt it. The leak in 1977 came on suddenly and it is reasonable to assume the separation of the 12-inch bell and spigat cast iron pipe occurred with a fairly short period of time before that.

9. P. 21 The leak that Mr. Ted Williams investigated for the Bozeman Creek Reservoir Association (I was out of the state when it happened) resulted from a venturi action of the 12-inch pipe drawing water through some talus left along the upstream interface of the core wall and the north bank. The glory hole type of leak was at a point where timber supports for the old wooden spillway are removed and apparently left a weak spot for the water to enter the face of the dam. We excavated the glory hole entrance, and it only went into the face of the dam three to four (3-4) feet. The area has been completely excavated and replaced. A gravel and sand filter was put in along the interface of the core wall and the natural bank material. The rest of the area was filled with local clays similar to the dam material and mechanically compacted to the same densities as the rest of the dam. All lifts were about 6-inches thick and checked with a nuclear densometer before the next lift was placed. Bentonite was mixed into the fill in a 5% Bentonite 95% native clay mixture.

Conclusions:

In answer to 3.2 Recommendations we offer the following:

1. If any one has suggestions on the emergency action plan, we will be happy to update our plan. I do not subscribe to the test idea but am willing to submit the plan to all who might be involved and hold a meeting of those responsible to work out details.

2. I have looked into the seepage area with our consultants, and we can put in a drain and fill the area so that water will not stand on the downstream face of the dam.

3. Survey monuments can be placed and read annually during the inspection by City and USFS personnel.

4. We want to rehabilitate the outlets as soon as it is determined that the owners can and are willing to stand the cost.

5. We will chemically grout the entire dam as needed as soon as the pipes are repaired.

6. Previous inspection by Northern Testing did not indicate a problem. We have asked for and just received a proposal by Northern Labs for geophysical investigations to complete our study of Mystic Lake Dam. Periodical inspections will be continued.

7. We accept the PMF designed by the SCS, see enclosed letter, as a reasonable handling of a storm we feel is geographically impossible.

We need the reservoir for domestic and agricultural water storage but would need to obtain financing if extensive rebuilding occurs.

Mr. Sidney Knutson
December 13, 1979

We have discussed your final draft with the State DNR & C, USFS, Mr. Ted Williams, Montana State University, and the Bozeman Creek Reservoir Association.

We respectfully submit these comments and enclosures in answer to your request of November 19, 1979.

Sincerely,

Arthur Van't Hul
City Engineer

AVH/crc

Enclosures

cc Dick Creed, Forest Engineer, Gallatin National Forest
Roger White, Hydraulic Engineer, F. S. Regional Office
Larry Tegg, Montana Dept. of Natural Resources & Conservation
Glen McDonald, Montana Dept. of Natural Resources & Conservation
Bill Hoffman, Bozeman Creek Reservoir President
Don Strang, Water Supt., City of Bozeman
John Dolan, U. S. Forest Service
Ted Williams, Dept. of CE & EM, MSU
Arthur Van't Hul, City Engineer
John McCulloch, Forest Service

United States Department of Agriculture
Soil Conservation Service
P. O. Box 970
Bozeman, Montana
59715

December 13, 1979

Art Van't Hul
City Engineer
City of Bozeman
Bozeman, MT 59715

Dear Mr. Van't Hul:

Attached are the computations you requested for Mystic Lake.

The freeboard hydrograph was developed from the 6-hour probable maximum precipitation which was estimated from Weather Bureau Technical Paper 38. Computations followed procedures in SCS National Engineering Handbook, Section 4, Hydrology, Chapter 21. This hydrograph is the one we would use to size the emergency spillway to prevent overtopping under our present criteria (Technical Release 60).

The breach hydrograph peak discharge at the dam is $Q_{max} = 65\ H^{1.85}$ where H is the depth of water at the dam at time of failure. This is according to our latest procedure outlined in Technical Release 66. If you assumed that H is equal to the maximum height of the dam, which is 58.5 feet according to our information, then Qmax would equal 120824 cfs.

The routing of this peak would be done taking into account valley storage down to the point in question. We do not have the data to do this at the present.

Sincerely,

Homer C. Moore
State Conservation Engineer

Attachments

cc: Stanley Hamilton, Hydraulic Engineer, SCS, Bozeman, MT

SCS-ENG-319
Rev. 1-70
Filg Code ENG-13-11

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

FREEBOARD HYDROGRAPH COMPUTATION

DATE 12-12-79
COMPUTED BY S.M. Hamilton
CHECKED BY

WATERSHED OR PROJECT Bozeman Q

STATE Montana

STRUCTURE SITE OR SUBAREA Mystic Lake

DR. AREA 4.94 SQ. MI. STRUCTURE CLASS C (High Hazard)

T_c 1.5 (See attached) HR. STORM DURATION 6 HR.

POINT RAINFALL 11.9 IN. (Weather Bureau, TP 38) Probable Max Precip.

ADJUSTED RAINFALL:

AREAL: FACTOR 1 IN. 11.9

DURATION: FACTOR 1 IN. 11.9

RUNOFF CURVE NO. 62

Q 6.78 IN. Runoff

HYDROGRAPH FAMILY NO. 2-3, Use 2 (Fig 21-3)

COMPUTED T_p 1.05 HR. 0.7(T_c)

T_o 4.79 HR.

$P^* = 1.23$ (Table 21.14)
$P^*/P = .103$ (Rainfall Ratio)
Time Ratio = .7985 (Table 21.15)
$T_o = .7985(6) = 4.79$

(T_o / T_p): 4.75/1.05

COMPUTED 4.56 ; USED 4 (Table 21.16)

REVISED T_p 1.20 4.79/4

$q_p = \frac{484A}{\text{REV. } T_p} = 1992.47$ CFS.

$(Q \times q_p) = 13508.92$ CFS.

t(COLUMN) = (t / T_p) REV. T_p q(COLUMN) = $(q_c / q_p) \times Q \times q_p$

Q(COLUMN) = $(Q_t / Q)Q$ (Tables 21.17)

	$t = t/T_p \times$ Rev. T_p	$q = (q_c/q_p)(Q)(q_p)$	$Q_t = (Q_t/Q)Q$
	t HOURS	q CFS	Q INCHES
1	0	0	0
2	0.4	27	
3	0.8	122	
4	1.2	486	
5	1.5	1743	
6	1.9	4485	
7	2.3	6768	
8	2.7	7430	-Peak
9	3.1	6754	
10	3.5	5701	
11	3.8	4836	
12	4.2	4080	
13	4.6	3701	
14	5.0	3107	
15	5.4	2634	
16	5.8	1986	
17	6.1	1337	
18	6.5	824	
19	6.9	500	
20	7.3	311	
21	7.7	176	
22	8.1	108	
23	8.4	68	
24	8.8	54	
25	9.2	41	
26	9.6	27	
27	10.0	14	
28	10.4	0	
29			
30			
31			
32			
33			
34			

All references-SCS National Engineering Handbook, Section 4, Hydrology, Chapter 21 except as noted. Rainfall Distribution used is Type B

Montana Bozeman Cr Watershed

S.M. Hamilton

Mystic Lake – Tc

Drainage Area = 4.94 Sq. Miles

Curve Number = 62

l (top divide to upper end of Lake) = 17708 feet = greatest flow length

Ave. Watershed Slope Y = 31.8 % (From Summation of Contour Length Method)

$$Tc = \frac{(l)^{.8}\left(\frac{1000}{CN} - 10\right)^{0.7}}{1140\,(Y)^{.5}} = 1.54$$

Use Tc = 1.5 Hrs (Ave Vel = 3.3 fps)

OK

CH2M HILL
engineers
planners
economists
scientists

February 1, 1980

S11779.P0

U.S. Army Corps of Engineers
Seattle District
P.O. Box C-3755
Seattle, Washington 98124

Attention: Ralph Morrison

Dear Mr. Morrison:

Subject: Mystic Lake Dam Inspection Report

After reviewing comments by the Forest Service and the City of Bozeman, we believe our report is accurate, factual, and needs no major changes. We do note that in a letter dated March 14, 1978, to Lewis Hawkes, U.S. Forest Service, Arthur Van't Hul, City Engineer, Bozeman, cites the potential for damage as a result of a breach of Mystic Lake Dam. We believe his assessment of the potential for downstream damage is based on engineering judgment, as is ours.

A study of flooding, as a result of a breach, combined with maximum spillway flows (overtopping) is desirable, and the report recommendations have been changed accordingly.

Sincerely,

Miles C. Bubenik
Project Manager

MCB:dgm

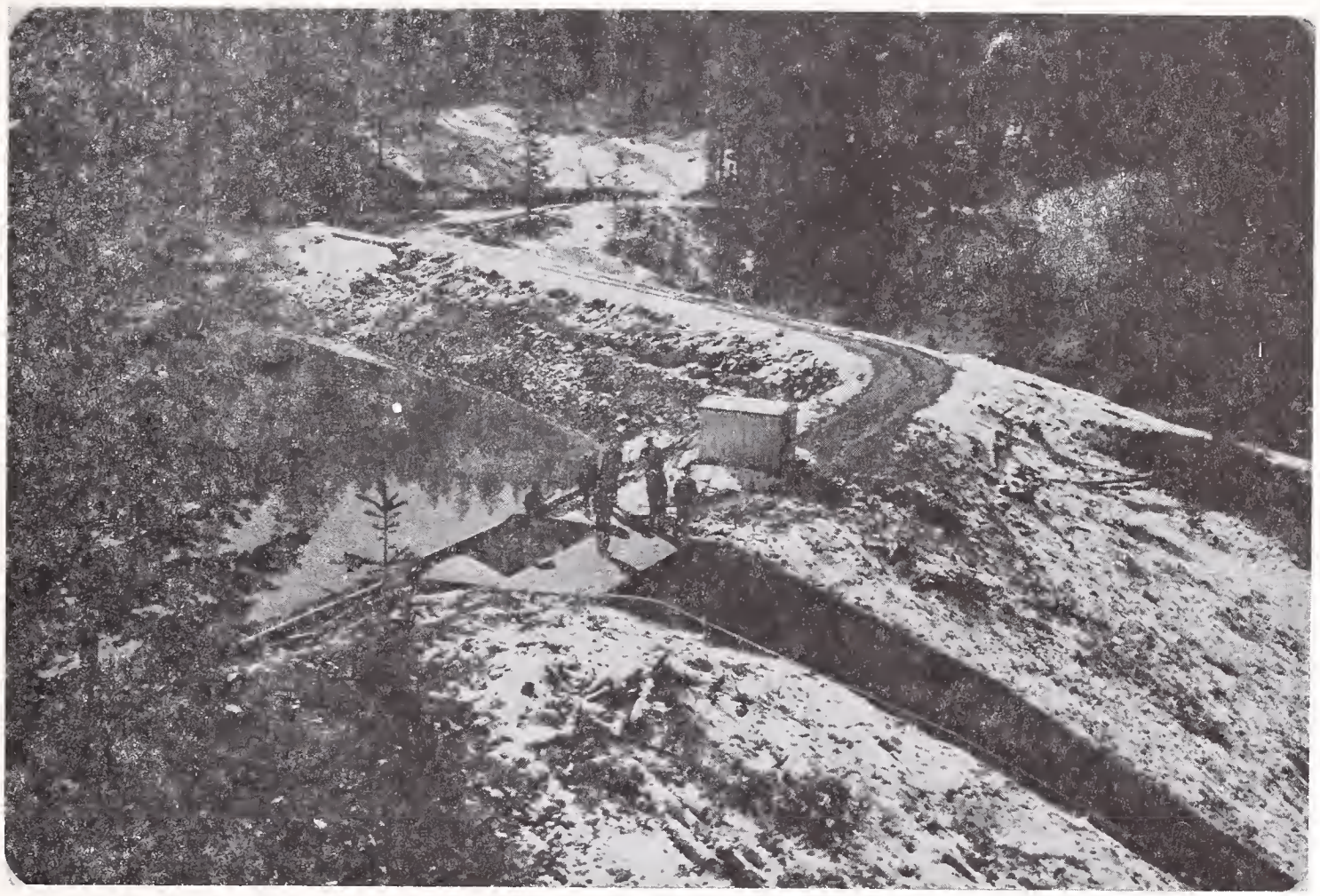


Photo 1 Overall view of Mystic Dam, spillway and gate control shed.

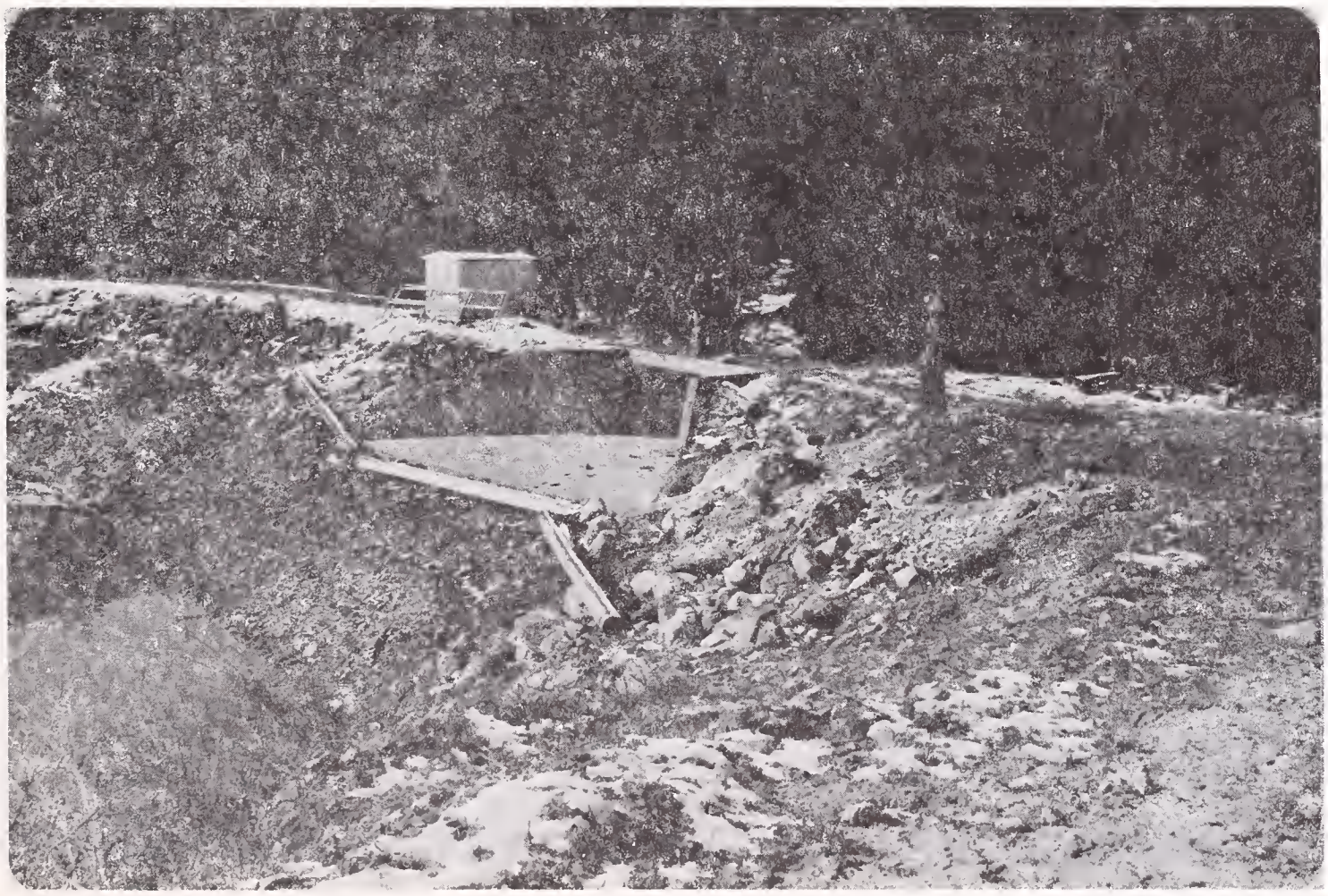


Photo 2 Right abutment and spillway approach.

Photo 3 Left abutment. Note division between original construction and later dam raise.

Photo 4 Spillway and low level conduit discharge.

Photo 5 View of downstream left abutment.

Photo 6 View of downstream slope and ridge between embankments.

Photo 7 Closeup of riprap.

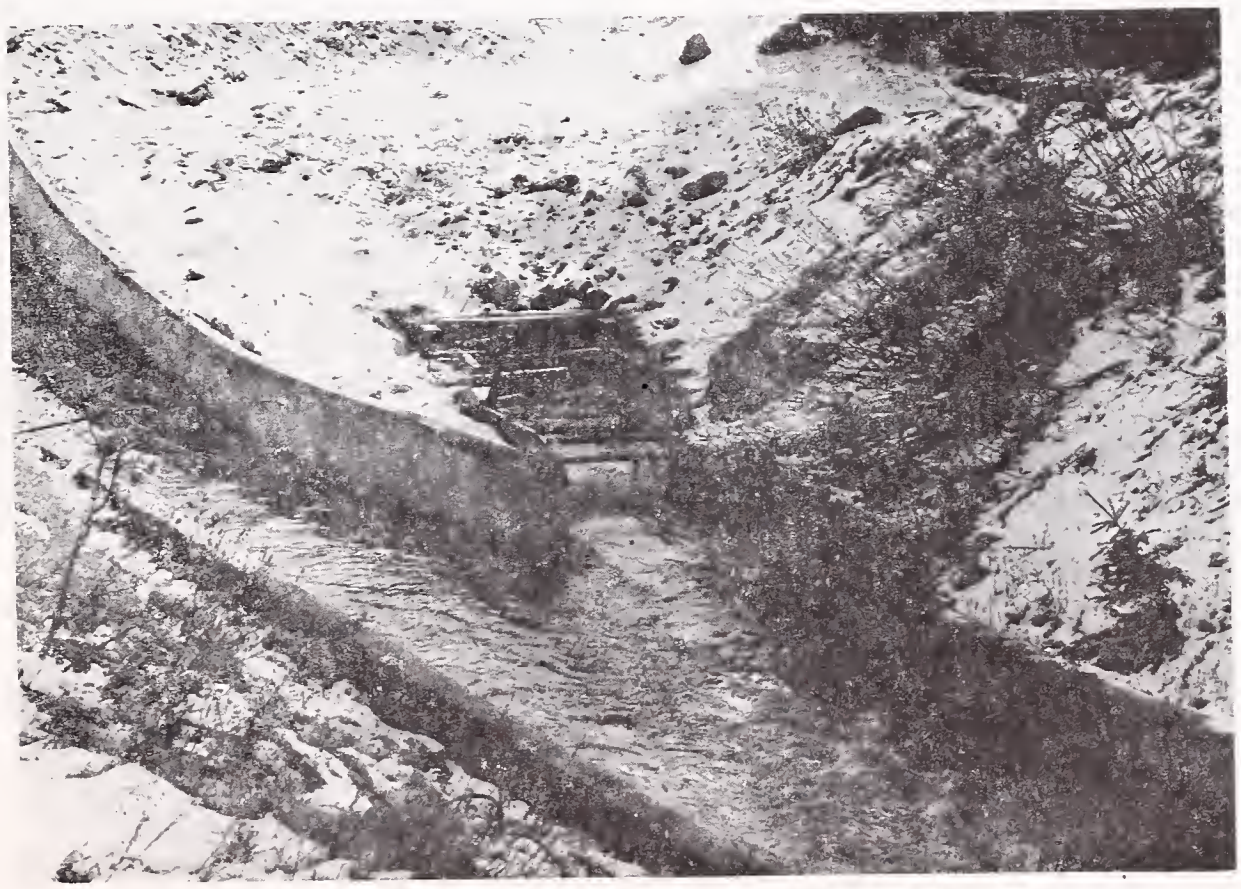
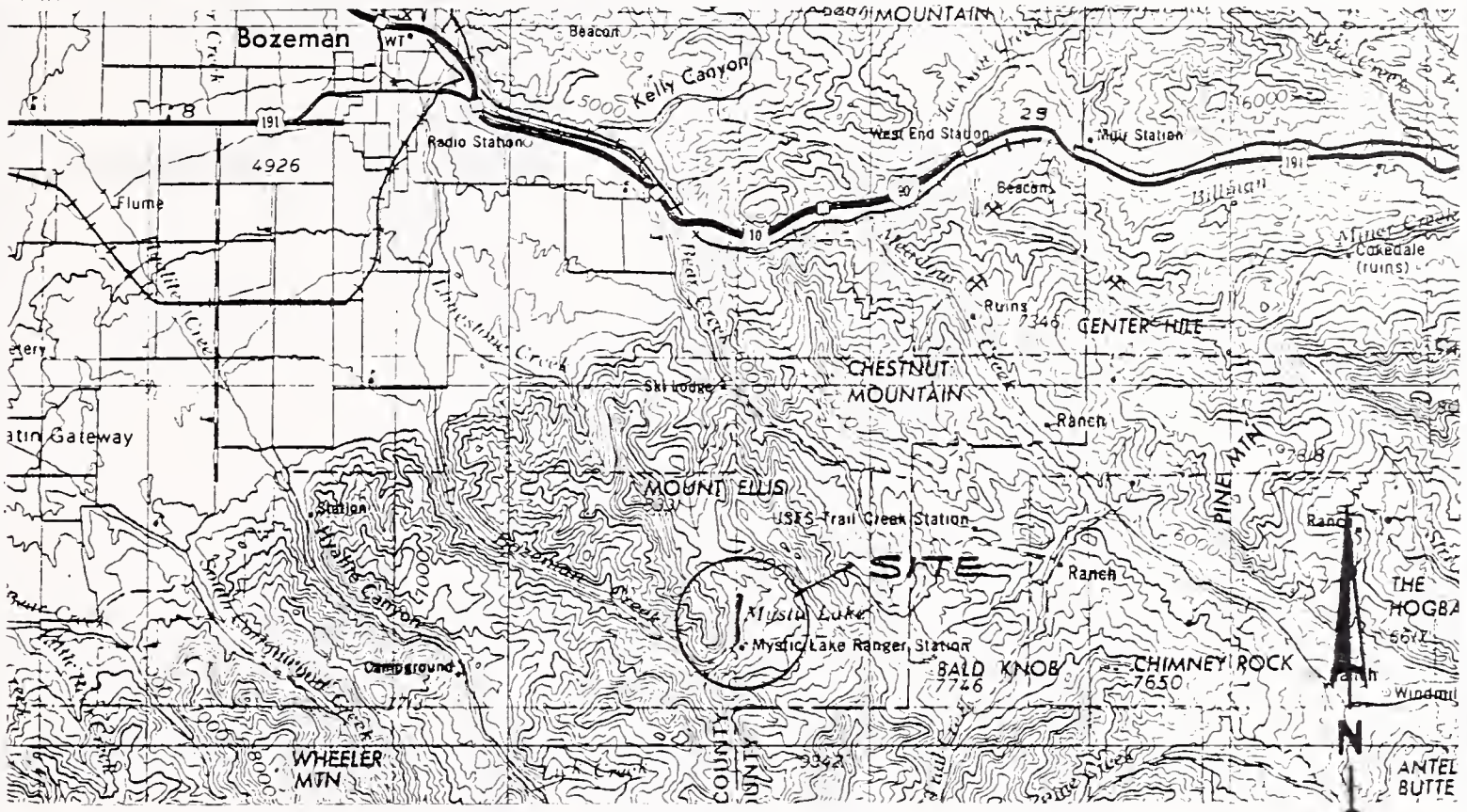


Photo 8 Spillway and low level outlet discharge.



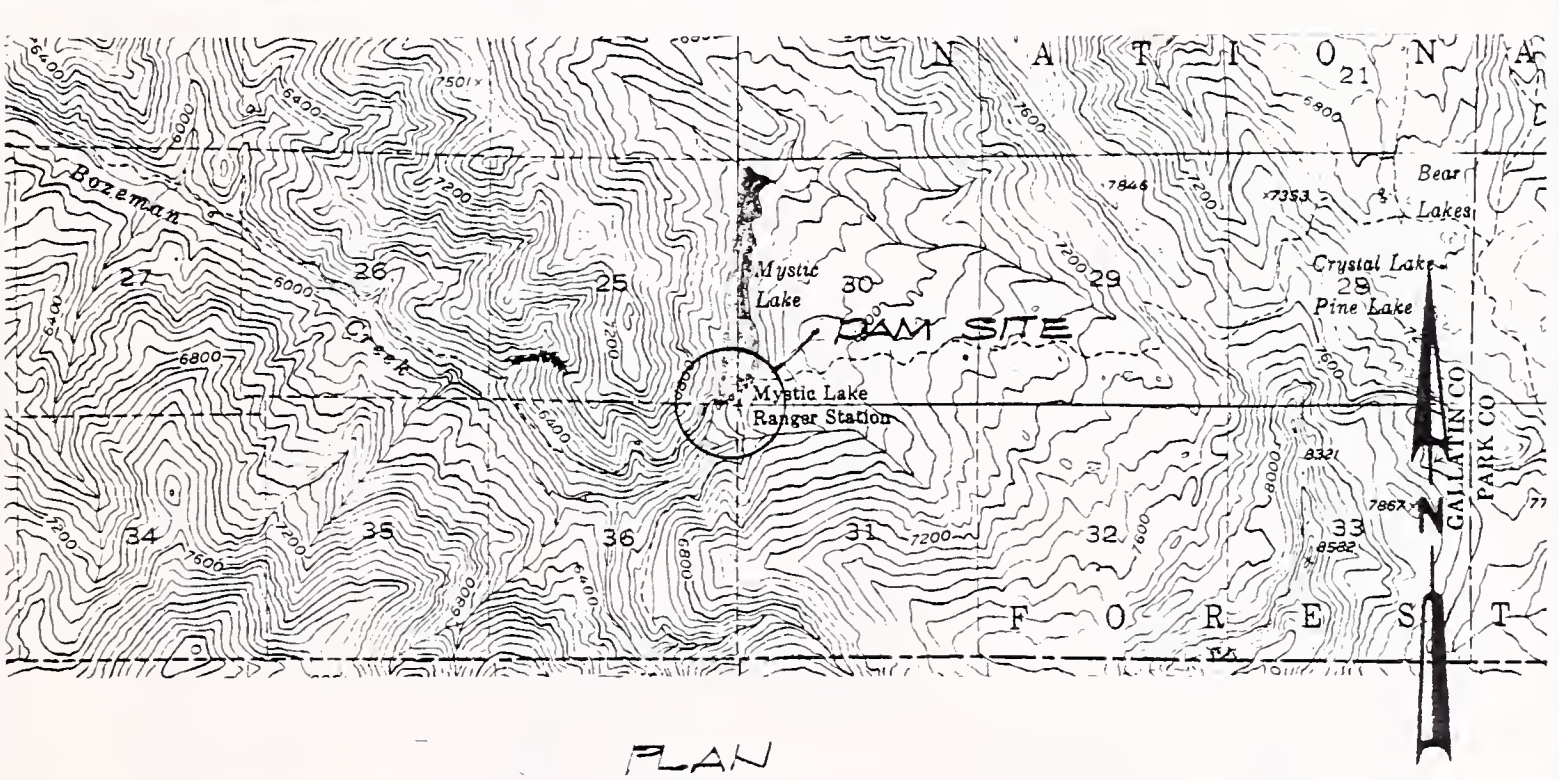


PLATE 1

MYSTIC LAKE DAM

VICINITY MAPS

CH2M HILL

MYSTIC LAKE

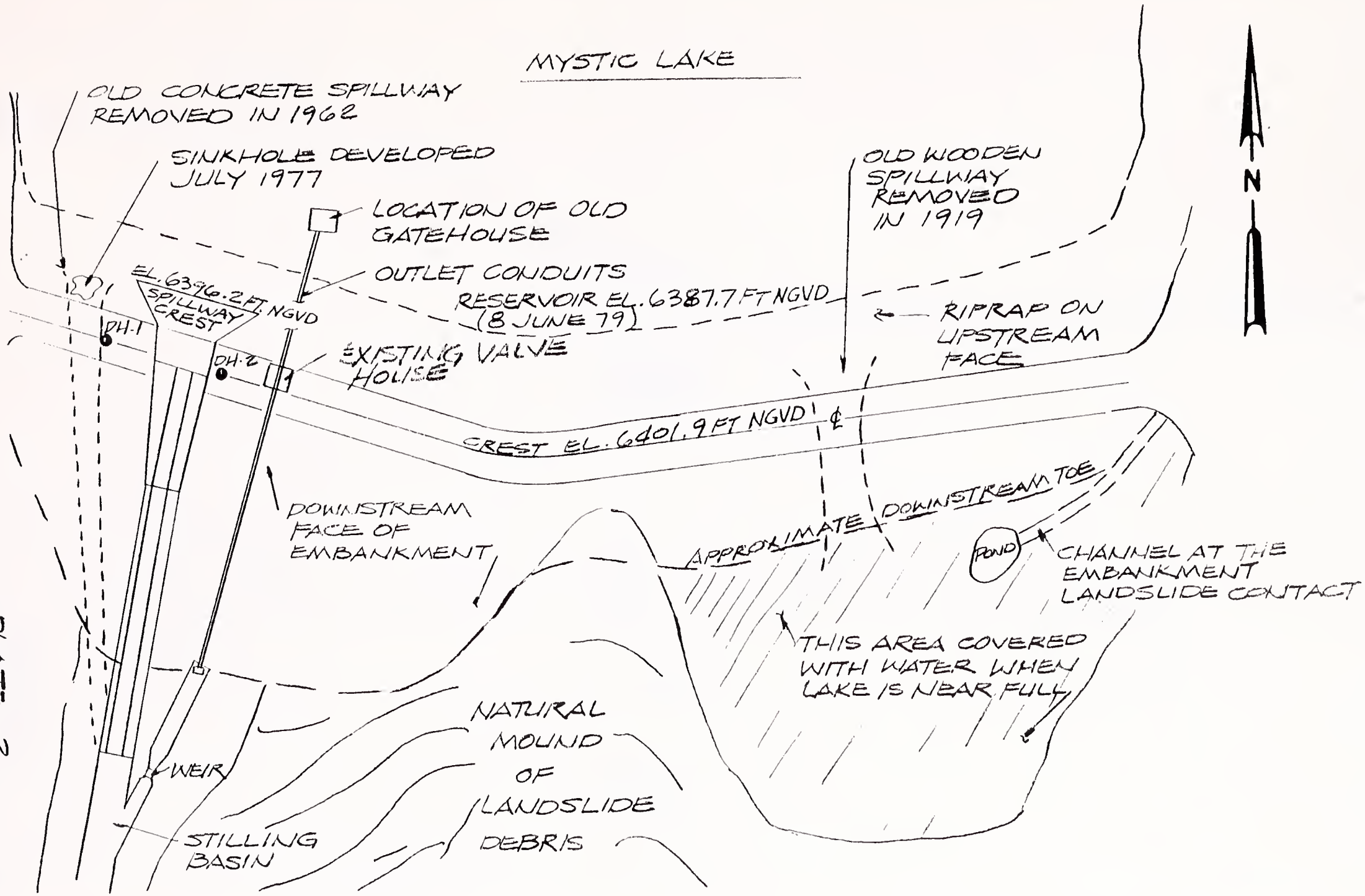
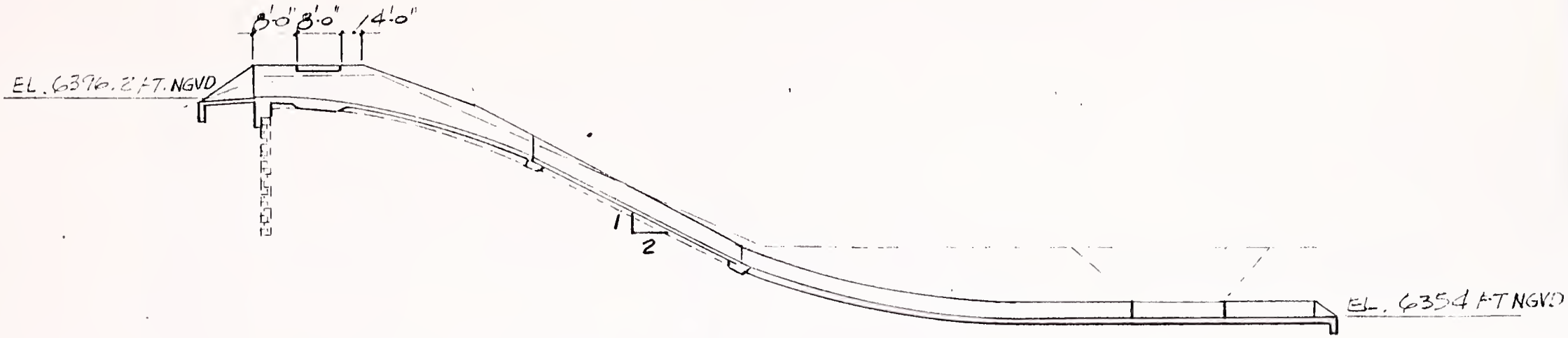


PLATE 2

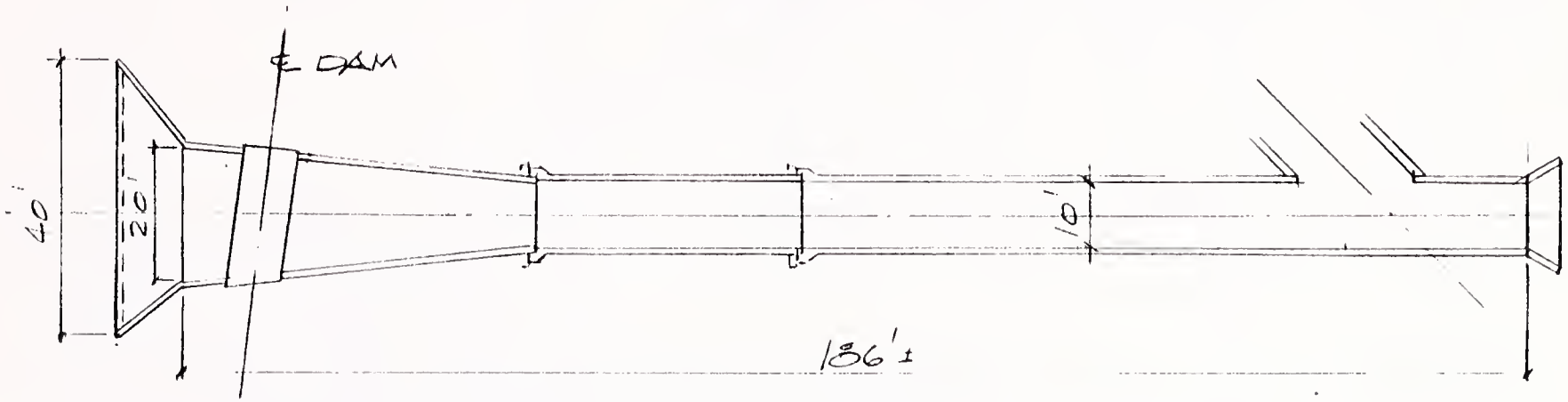
MYSTIC LAKE DAM

SITE PLAN

CH2M HILL



PROFILE
N.T.S.



PLAN
N.T.S.

PLATE 3
MYSTIC LAKE DAM
SPILLWAY PLAN & PROFILE

CH2M HILL

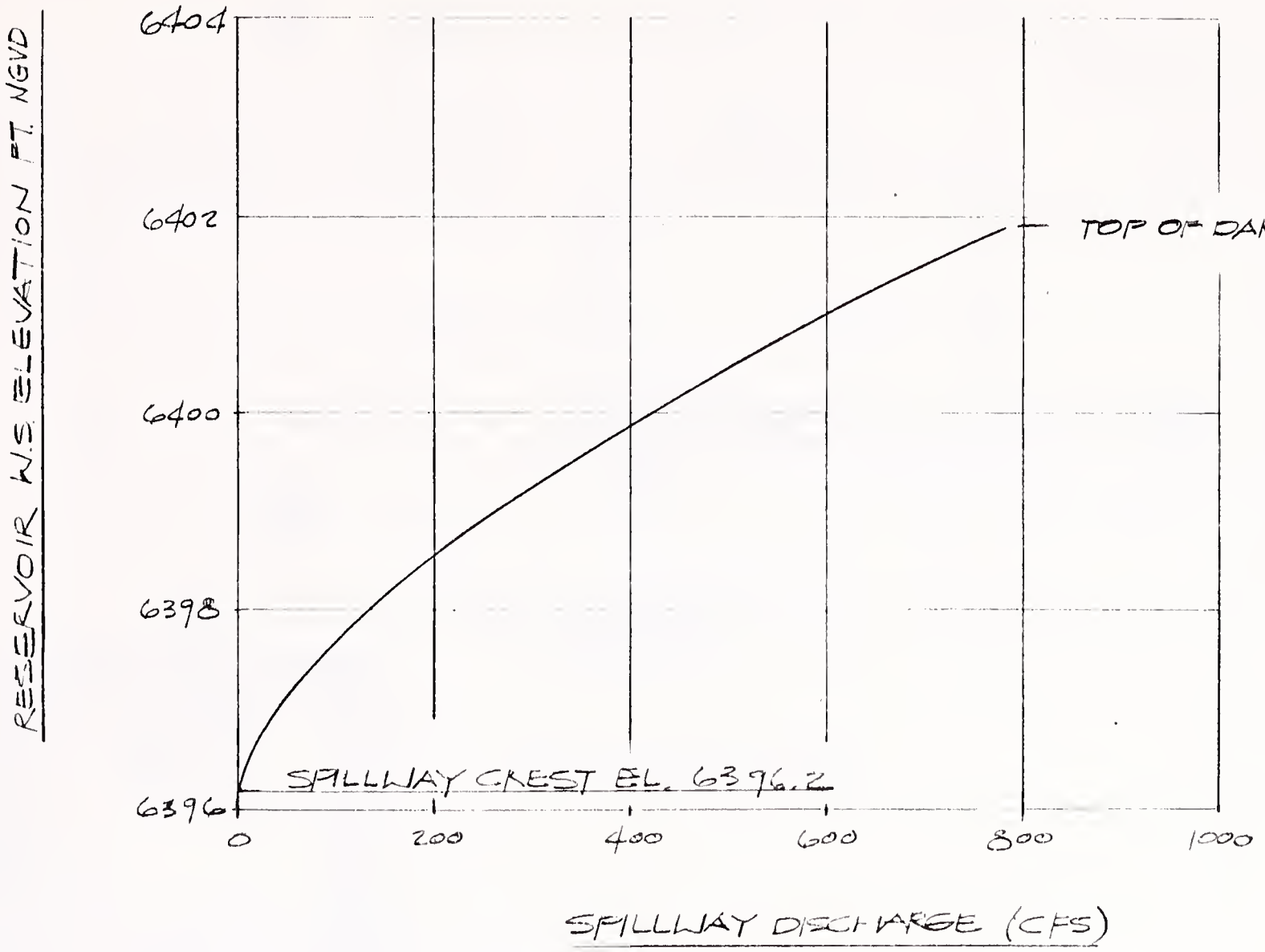
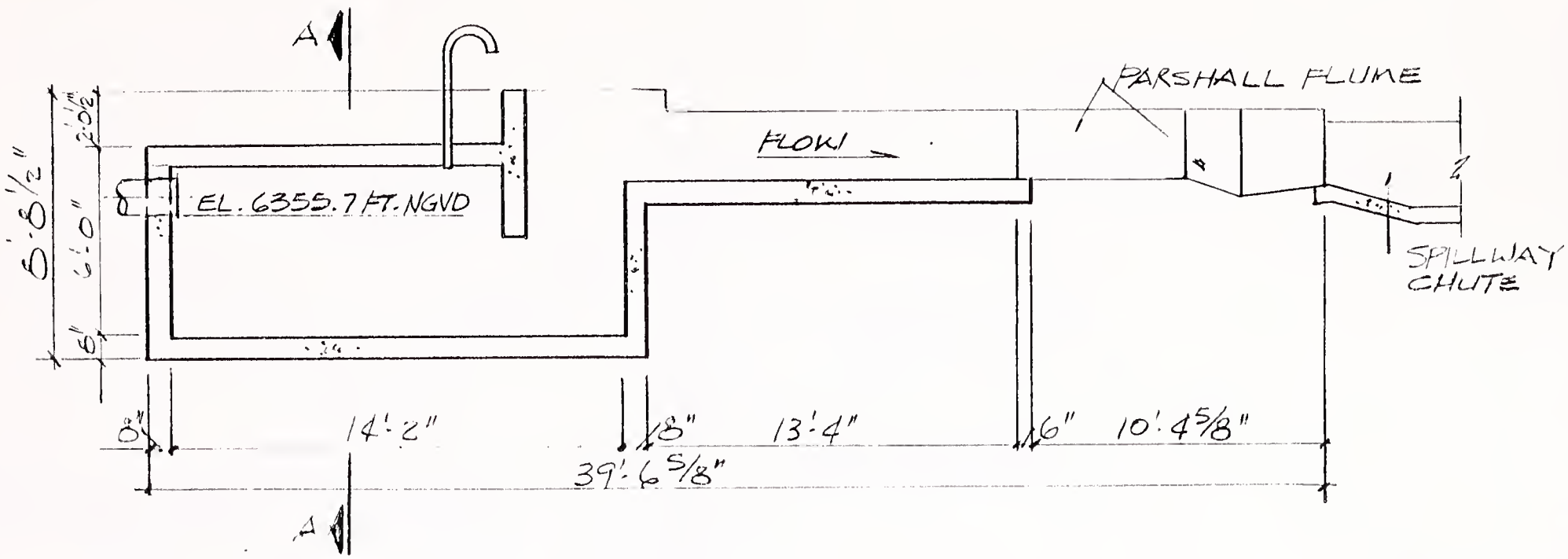


PLATE 4

MYSTIC LAKE DAM

SPILLWAY RATING CURVE

CH2M HILL



SECTION
N.T.S

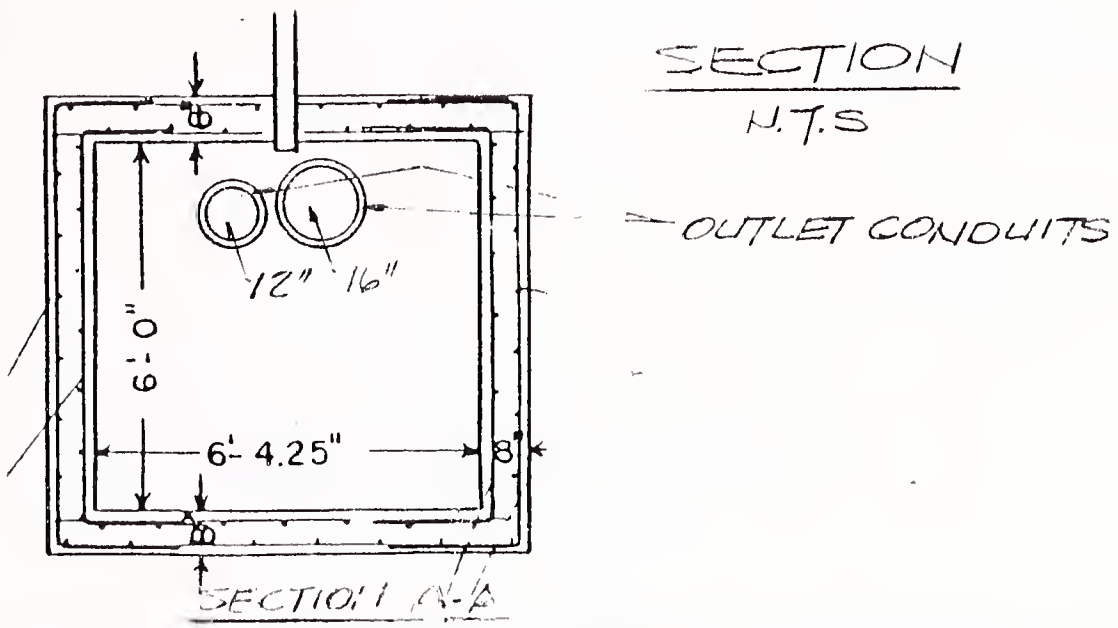
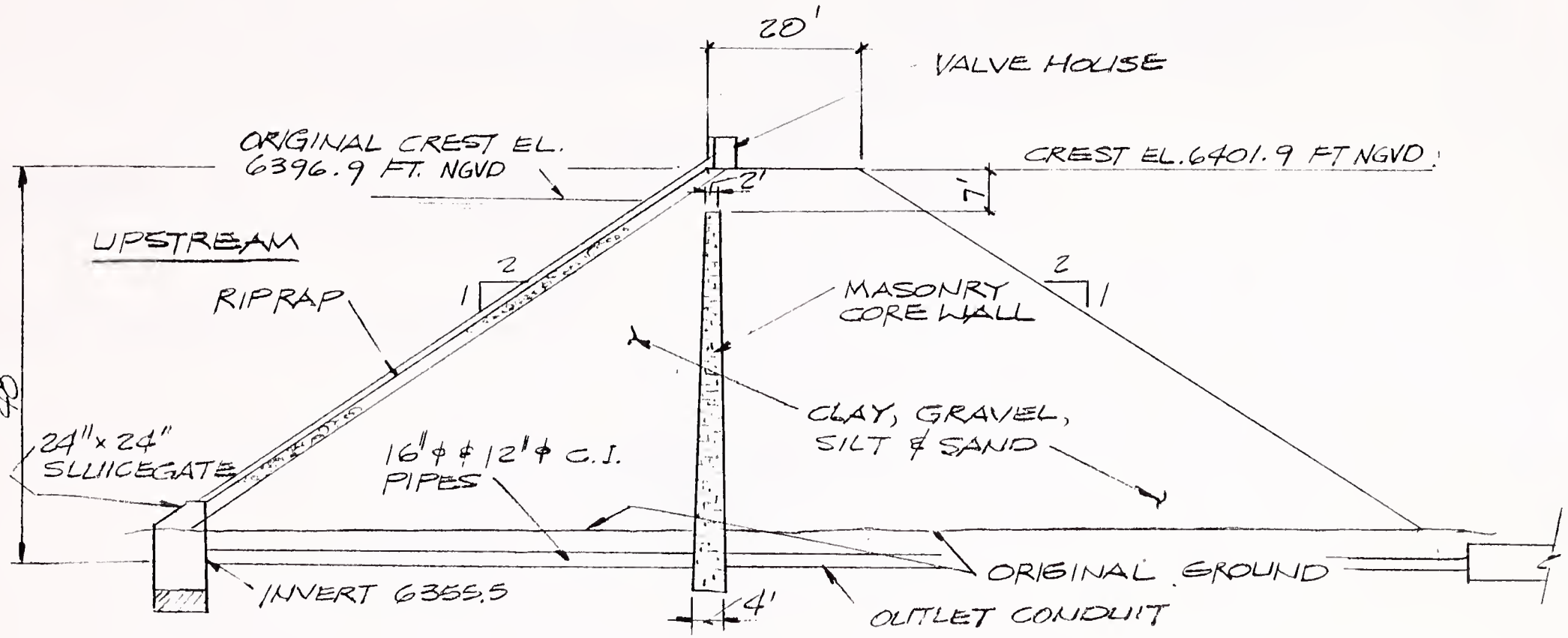


PLATE 5
MYSTIC LAKE DAM
OUTLET BOX SECTION

CH2M HILL



SECTION

N.T.S.

NOTE:

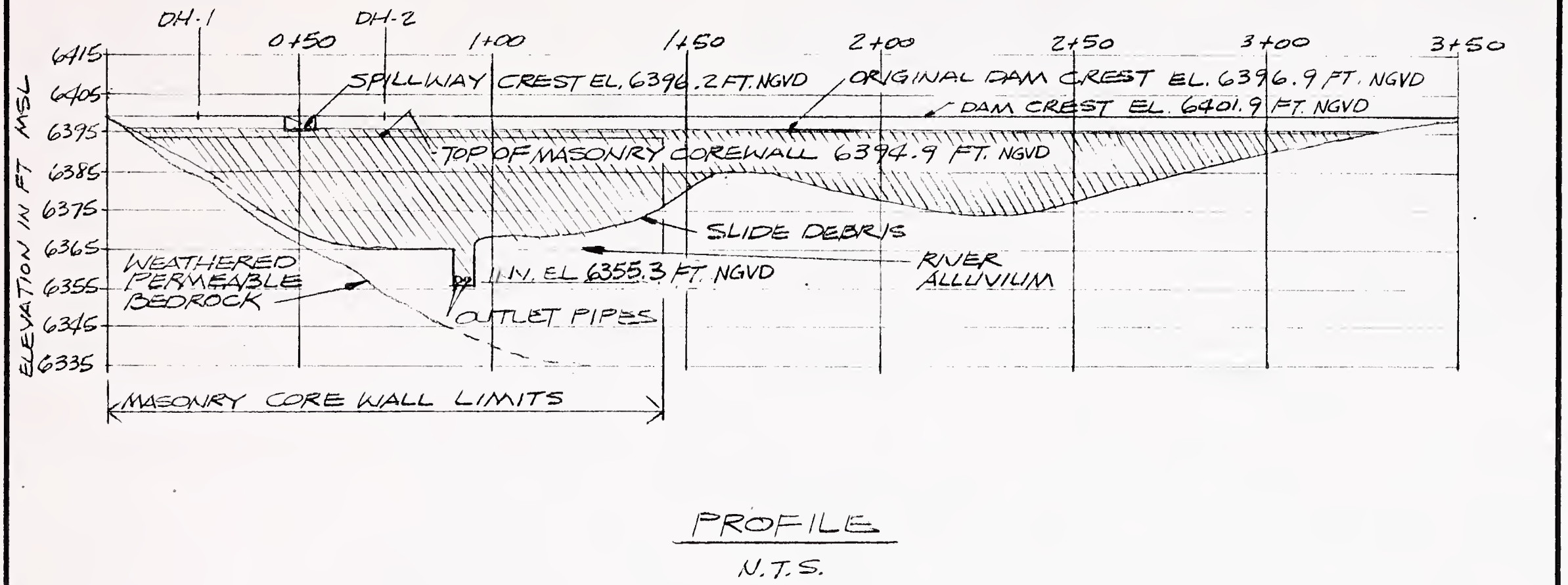
DAM RAISED APPROX. 3 FEET IN 1932 AND 2 FEET IN 1959

PLATE 6

MYSTIC LAKE DAM

DAM SECTION

CH2M HILL



PROFILE

N.T.S.

PLATE 7

MYSTIC LAKE DAM

DAM PROFILE

CH2M HILL